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SIMULATION OF SEQUENTIAL TESTS.(U)
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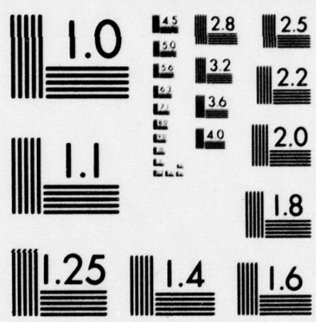
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9 REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AMSAA Technical Report No. 241	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER: 14 AMSAA-TR-241	
4. TITLE (and Subtitle): 6 Simulation of Sequential Tests.	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 William J. Broemm	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Director, US Army Materiel Systems Analysis Activity, ATTN: DRXSY-RE, Aberdeen Proving Ground, MD 21005	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DA Project No. 16 1R765706M541
11. CONTROLLING OFFICE NAME AND ADDRESS: 12 56p. 11	12. REPORT DATE: Nov[redacted]978
	13. NUMBER OF PAGES: 65
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Commander, US Army Materiel Development and Readiness Command, 5001 Eisenhower Avenue, Alexandria, VA 22333	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Probability Ratio Sequential Tests
Discrimination Ratio
Accept-reject criteria

theta 1

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A computer program is presented which simulates a Probability Ratio Sequential Test (PRST) plan from MIL-STD 781C. Upon selection of an applicable test plan and a lower test MTBF (θ_1), the simulation determines, for a chosen range of true MTBFs, ~~(1)~~ the probability of reaching maximum (total) test time before making a decision (to either accept or reject equipment) and ~~(2)~~ the probability of reaching the last failure in the test plan. Examples are available from selected test plans.

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ACKNOWLEDGMENTS

I wish to thank Harry B. Tanner for his ideas concerning the several "weighting schemes" and for his helpful suggestions regarding the CALCOMP plotting subroutines. I also wish to thank Gregory J. Gibson for getting me started on the project.

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SIMULATION OF SEQUENTIAL TESTS

1. INTRODUCTION

The computer program presented in this paper is offered as an aid to test planners and those who are concerned with the application of the Reliability Design Qualification and Production Acceptance Tests (Exponential Distribution), more specifically, the Probability Ratio Sequential Test (PRST) plans from MIL-STD-781C.

The PRST plans, which come under the category of statistical test plans, should be employed when a sequential test plan with minimal decision risks (10 to 20 percent) is desired. In the main, the PRST plans would be preferred to the fixed length test plans when the objective of the test is to accept material with a high mean-time-between-failures (MTBF) or reject material with a very low MTBF as quickly as possible.[1]

In view of these considerations, the utilization of the methodology proposed should permit the test planner, equipped with a reasonable amount of practical experience with the PRST plans, to make certain probabalistic statements regarding termination points in the plans, namely (1) the likelihood of reaching the last failure and (2) the likelihood of reaching the maximum test time.

Historically, the PRST plans have no provision for establishing a definitive estimate of the true MTBF of an item prior to testing. Therefore, the expected time required for test completion may vary significantly. Consequently, program costs and schedules have to be planned to compensate for this range of uncertainty. However, with the help of the methodology delineated herein, one may be able to choose an appropriate test plan from MIL-STD-781C, select a lower test MTBF (θ_1), specify a realistic range of true MTBFs for consideration, implement the simulation, and finally obtain measures of the two likelihood estimates aforementioned, all of this in order to reduce the range of uncertainty and therefore, minimize program cost overruns.

2. APPLICATION OF MIL-STD-781C AND THEORETICAL CONSIDERATIONS

A typical PRST plan from MIL-STD-781C, regardless of the total number of failures and the total test time in the plan, will basically assume an appearance as depicted in Figure 1. Given that the decision risks, discrimination ratio, total number of failures, and accept-reject criteria are all in harmony, of concern is not the general shape or length of the PRST arrow (shaded area) but the two termination vectors located in the arrowhead. For simplicity, we may designate the last failure as F_L and the maximum total test time as T_M. The problem, then,

[1]Proposed MIL-STD-781C Reliability Design Qualification and Production Acceptance Tests: Exponential Distribution.

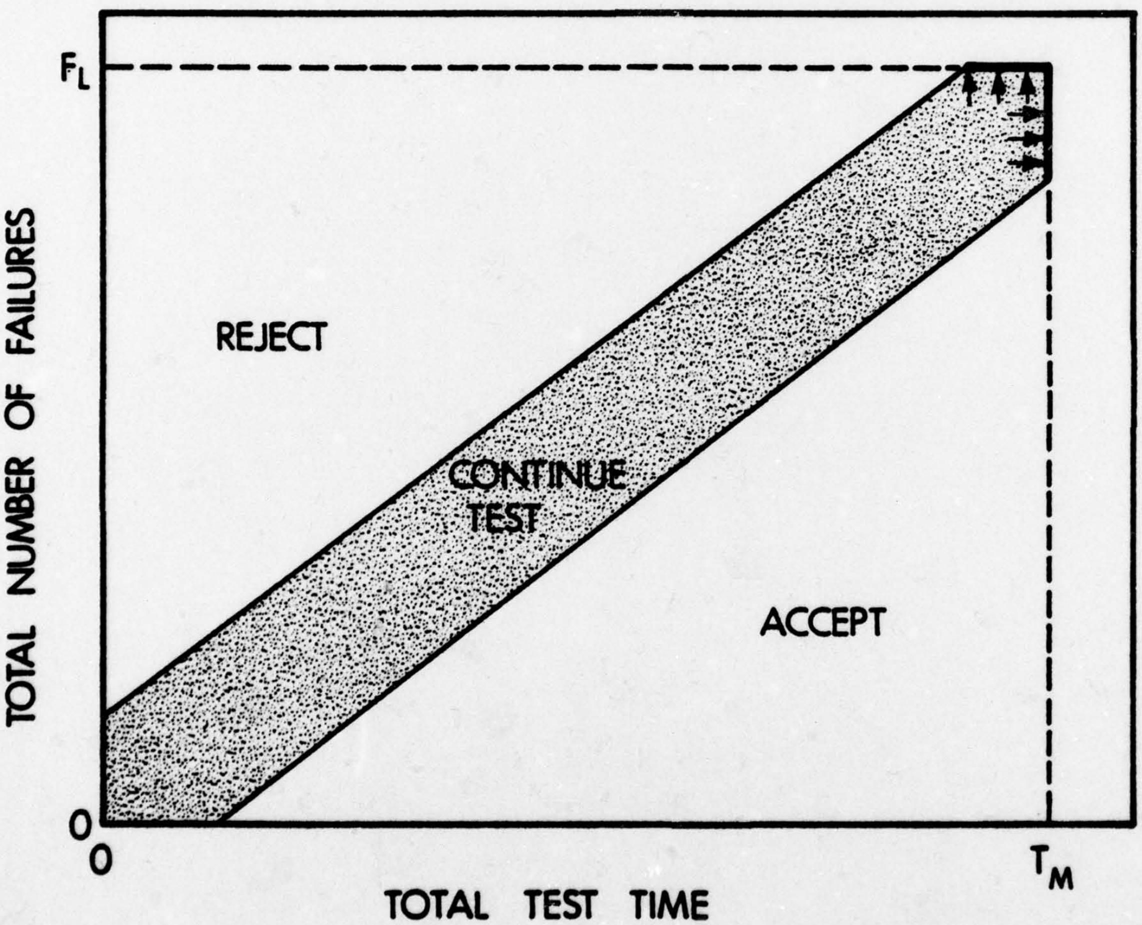


Figure 1. A Generalized PRST Plan.

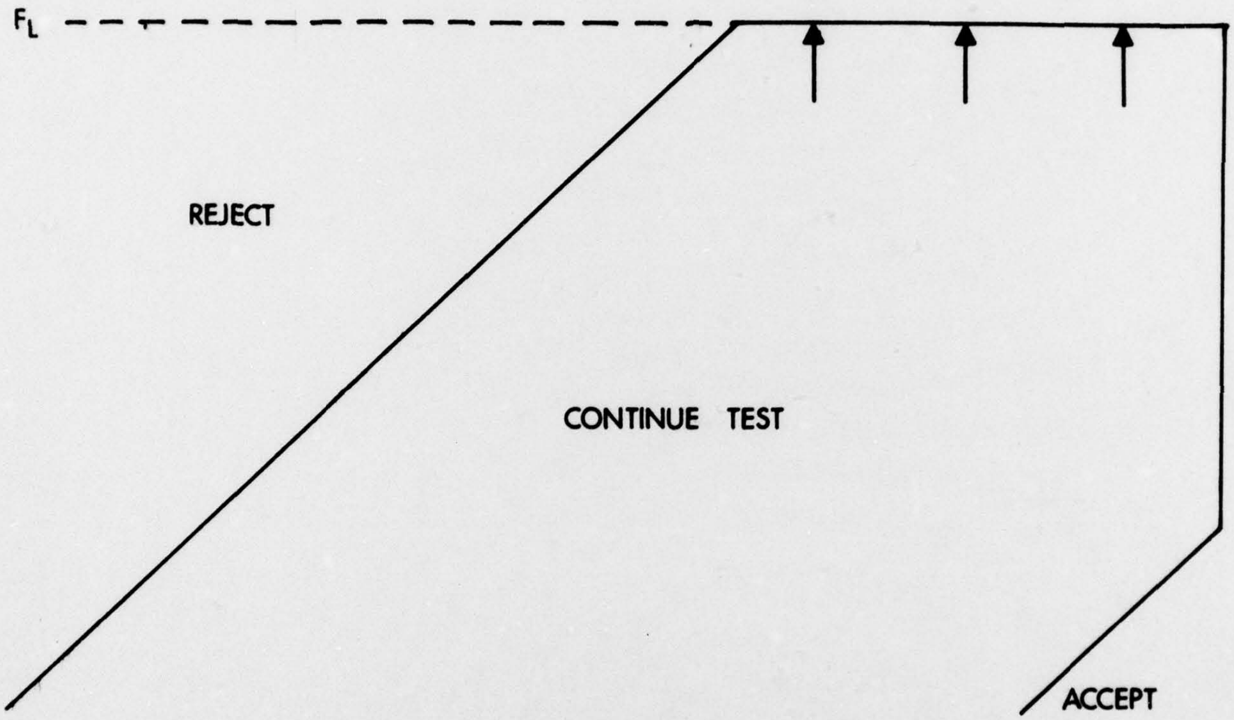


Figure 2. Last Failure Consideration.

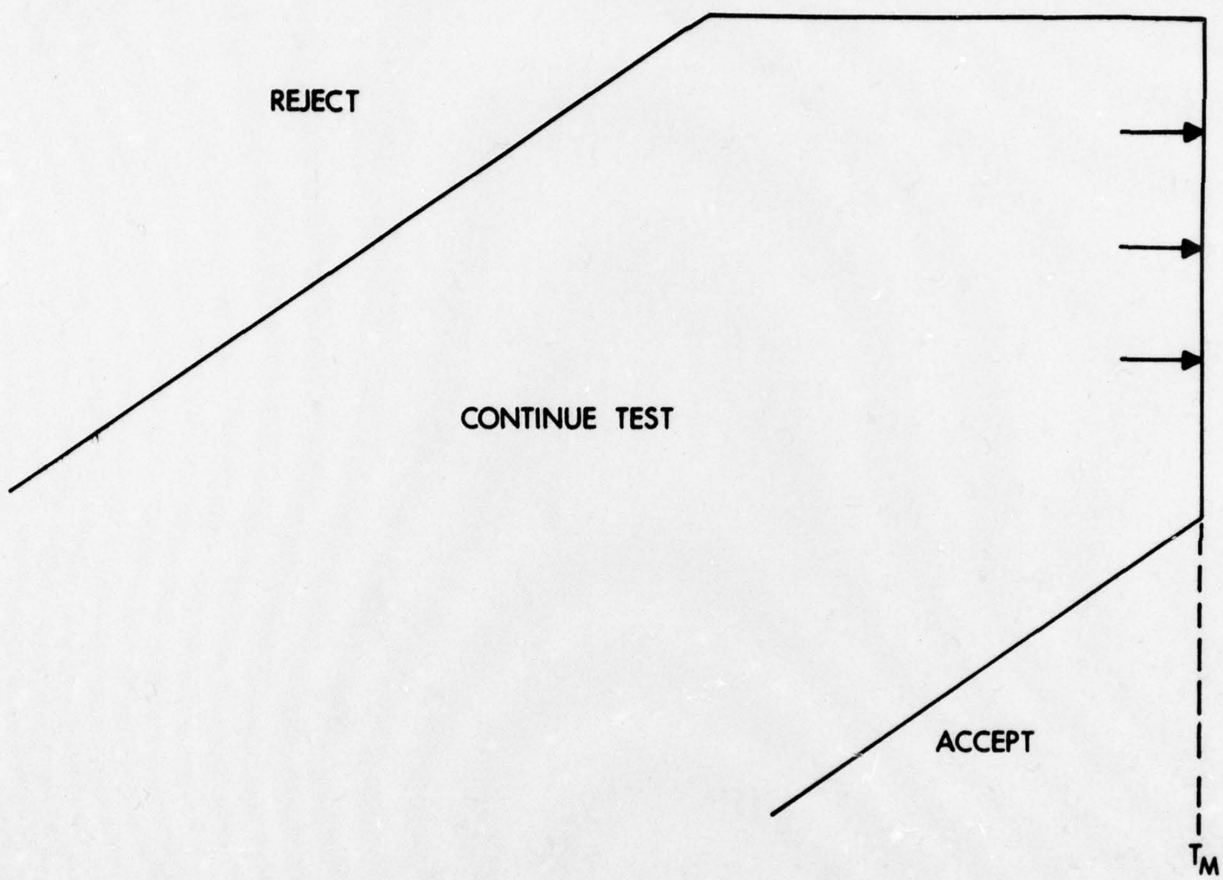


Figure 3. Maximum Test Time Consideration.

$$\underbrace{\frac{1}{16n}+\underbrace{\frac{1}{8n}+\underbrace{\frac{1}{4n}+\underbrace{\frac{1}{2n}+\frac{1}{n}+\frac{1}{2n}}_{\text{3 PTS}}+\frac{1}{4n}}_{\text{5 PTS}}+\frac{1}{8n}}_{\text{7 PTS}}+\frac{1}{16n}}_{\text{9 PTS}} = 1$$

Figure 4. Weighting Scheme.

SUBROUTINE SUB3

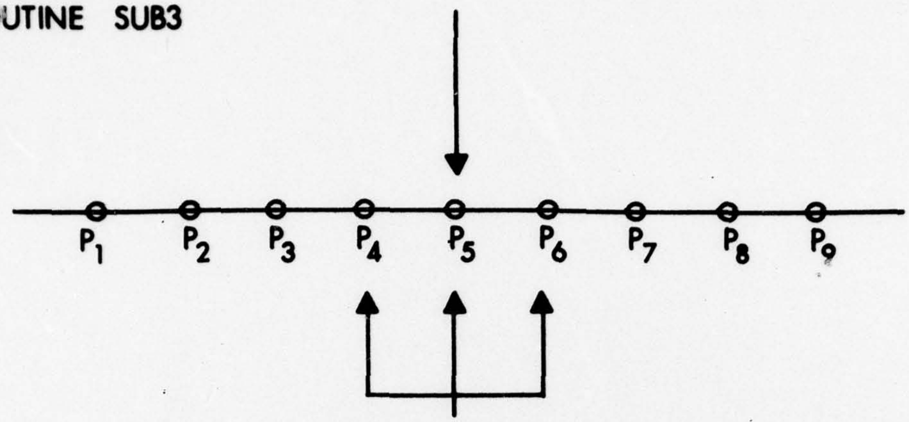


Figure 5. Curve Smoothing Scheme (3- Point)

SUBROUTINE SUB9

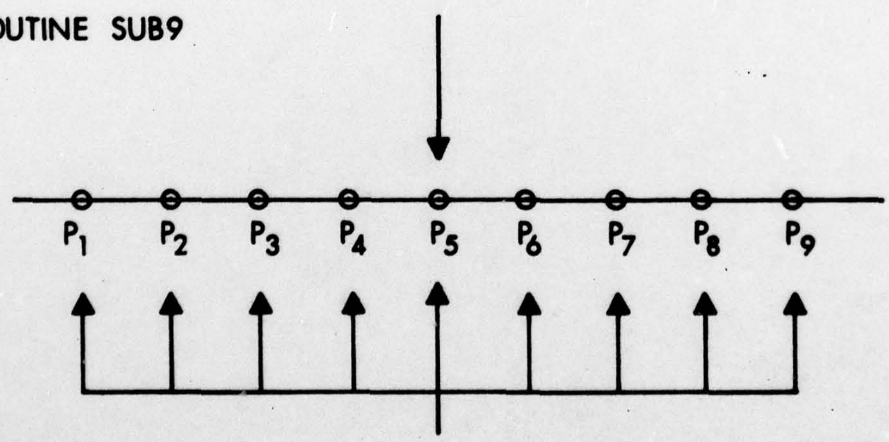


Figure 6. Curve Smoothing Scheme (9-Point)

becomes the following: When testing an item of equipment with the PRST plans, how often is the last failure reached? In other words, what is the likelihood of reaching F_L?

In a similar manner, when testing an item of equipment with the PRST plans, how often is the maximum test time reached? That is, what is the likelihood of reaching T_M? With these thoughts in mind, the purpose of the simulation, then, is to ascertain how often F_L and T_M are reached. (Figures 2, 3).

Once arrays of these likelihood estimates are determined for a representative range of true MTBFs, it may be feasible, strictly for the benefit of the CALCOMP plots, to effect minor changes to these arrays by employing a simple weighting scheme (Figure 4). By allowing a particular data point to have a weight of 1/n, successive neighboring data points in either direction can be assigned weights of 1/2n, 1/4n, 1/8n and so on. This scheme essentially permits valuable information to be used from data points in proximity (Figure 5, 6). If one is not so inclined toward implementing such curve-smoothing techniques, the unsanitized raw data points are still available.

3. PROCEDURE FLOWCHART

All that the user of the computer program (henceforth, referred to as program MS 781C) need be concerned with is contained in this section. An adherence to the principles set forth in the procedure flowchart (Figure 7) and the preparation of the data input cards for program MS 781C (Table 2) should permit the user to investigate a wide variety of options. There are two areas regarding input, though, that may require clarification - (1) the test plan matrix and (2) the accept-reject criteria.

A summary of the test plan matrix for MIL-STD-781C is shown below.

TABLE 1. MILITARY STANDARD 781 C

Test Plan Number	Maximum Number of Failures	Maximum Test Time (Theta One Multiple)	The Minimum Number of Failures From Which To Reach Maximum Test Time
1	41	49.50	36
2	19	21.90	15
3	16	20.60	12
4	8	9.74	5
5	7	10.35	4
6	3	4.50	2
7	6	6.80	3
8	3	4.50	2

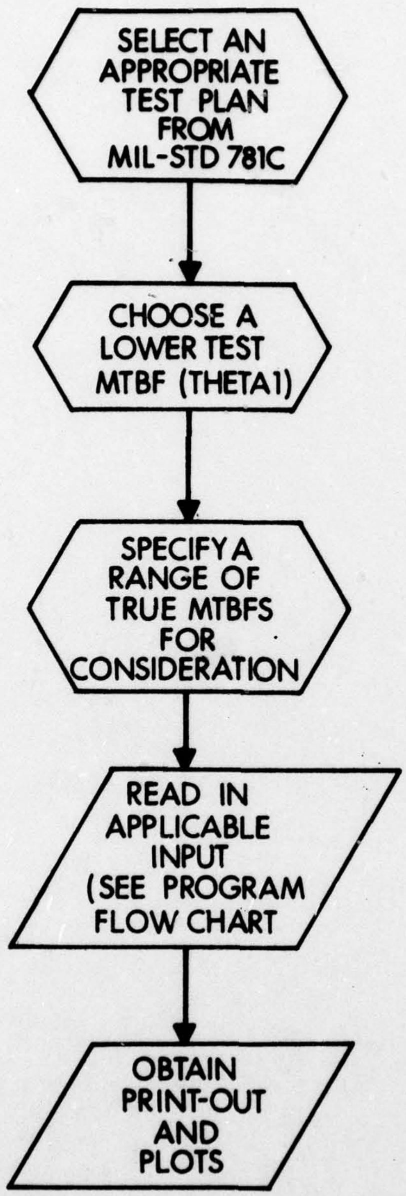


Figure 7. Procedure Flow Chart.

The test plan matrix (Table 1) is one of the required inputs to program MS 781C. It was defined in this way so that the user could specify the number of entries in the matrix (up to 25 entries as established in the program logic). Moreover, the test plan matrix was relegated to input status in order to provide flexibility for any user who chooses to submit a modified version of the test plan matrix, a version based on innovative truncation points perhaps.

Since the accept-reject criteria must be in accordance with the test plan matrix, it has also been placed in the domain of user-supplied input information. Care must be exercised, though, that the values for the reject line be input prior to the values for the accept line.

4. DESCRIPTION OF THE ALGORITHM

The essence of program MS 781C resides in a section of code (the algorithm) in the heart of the program. This set of instructions simulates the testing of an item of equipment using a typical PRST plan. The code, that is, set of instructions, makes use of two program counters. One counter corresponds to the last failure, F_L, and the other counter corresponds to the maximum test time, T_M. During each iteration of the simulation, an item of equipment can be either rejected, accepted, or put to further test (as exemplified by the continue test strip, Figure 1). If the item is rejected or accepted prior to reaching truncation, then no counters are incremented, and a new iteration is begun. If the item falls within the continue strip without a rejection or an acceptance, then another failure time is called for, and the above process is repeated.

In order to test against the maximum test time value, a particular failure time is compared with the T_M value. If that particular failure time is greater than or equal to the T_M value, then the T_M counter is incremented by one and a new iteration is begun. If that particular failure time is less than the T_M value, then another failure time is called for an queried in the same manner.

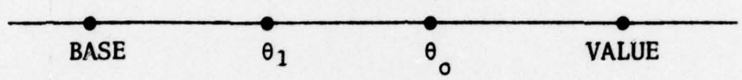
Similarly, in order to test against the last failure, a particular failure number is compared with the maximum failure number, F_L, to determine equality. If equality exists, then the F_L counter is incremented by one and a new iteration is begun. If equality does not exist; that is, if the particular failure number is less than the F_L value, then another failure is called for and queried in the same manner.

Now, if we allow each iteration to be an independent event, and if we conduct a large number of these trials, then the F_L and T_M

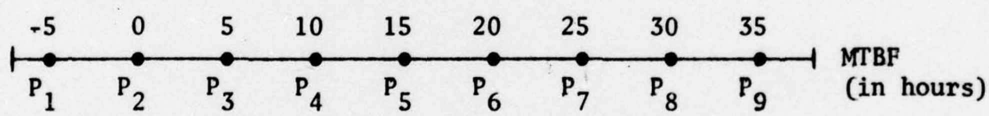
counters can be shown to be likelihood estimates for reaching the last failure and the maximum total test time, respectively. Furthermore, these likelihood estimates can be viewed in probabalistic terms.

5. RECOMMENDATIONS FROM COMPUTATIONAL EXPERIENCE

Once a PRST plan has been chosen and a value for the lower test MTBF (THETA ONE) has been designated, the only values that may require prudent selection are the three input parameters BASE, VALUE, and DELTAX (see Table 2, Appendix 1). Clearly, one would be interested in examining a range of true MTBFs encompassing both the lower test MTBF and the upper test MTBF (THETA ZERO). Something like the following might be of interest:



A problem may surface toward the lower end of the range of true MTBFs, though, if a value for the increment (DELTAX) is chosen too large. This problem could arise in subroutine SUB 9 where a neighborhood of nine (9) points is operated on:



For example, with a BASE MTBF of 15 hours and a DELTAX increment of 5 hours, the "lower-end" MTBF could attain a negative value, thereby creating a failure mode. However, the program logic is set up to handle this problem and will respond with a diagnostic to the user.

6. ILLUSTRATIVE EXAMPLES

In order to exemplify the range of possibilities that exists among the PRST plans, consider test plans II and VI (Table 3).

TABLE 3. COMPARISON OF TEST PLANS II AND VI

	Decision Risks	Discrimination Ratio	Total Number of Failures	Total Test Time
Test Plan II	20%	1.5:1	19	$21.90*\theta_1$
Test Plan VI	20%	3.0:1	3	$4.50*\theta_1$

Both test plans are based on the same risks. However, they differ in at least two respects: Test Plan VI has twice the discrimination ratio as Test Plan II, while Plan II is based on approximately six times as many failures as Plan VI.

Table IV below demonstrates simulation results for both plans at two specific data points - THETA ONE and THETA ZERO. In each cell, the top number gives the probability of reaching the maximum test time, $P(T_M)$, while the bottom number gives the probability of reaching the last failure, $P(F_L)$.

TABLE 4. SIMULATION RESULTS FOR TEST PLANS II AND VI

TEST PLAN		@ THETA ONE	@ THETA ZERO
	II	$P(T_M) = .12$	$P(T_M) = .21$
		$P(F_L) = .12$	$P(F_L) = .08$
	VI	$P(T_M) = .13$	$P(T_M) = .39$
		$P(F_L) = .86$	$P(F_L) = .38$

7. SUMMARY

The purpose of this study has been to develop an algorithm that, with the aid of Monte Carlo simulation techniques, would allow one to formulate certain probabalistic statements regarding termination points in the PRST plans. The information derived from program MS 781C coupled with empirical data from practical field experience with the plans should permit the test planner to obtain a grasp on the likelihood of arriving at the concluding points in the plans. With this kind of information, the test planner may be able to minimize program costs due to personnel and materials and perhaps get a better handle on structuring test schedules.

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APPENDIX I

TABLE 2. DATA INPUT CARDS

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APPENDIX I

TABLE 2. DATA INPUT CARDS

Data Card 1

Field 1	MAXNRF (I10)	The maximum number of failures for the test plan.
Field 2	NRITER (I10)	The number of iterations for the simulation e.g., 2000 or 10,000.
Field 3	NRTP (I10)	The number of the test plan being implemented.
Field 4	NRPLNS (I10)	The number of plans in the test plan matrix (not to exceed 25).
Field 5	BASE (F10.2)	The lowest MTBF in the range of MTBFs considered e.g., if an MTBF range of 50-250 is desired, then BASE would be 50.
Field 6	VALUE (F10.2)	The highest MTBF in the range of MTBFs considered.
Field 7	DELTAX (F10.2)	The increment value between successive MTBFs.
Field 8	THETA1 (F10.2)	The lower test MTBF.

Data Card 2

This data card consists of the array containing the values for the reject line. Data must be arranged sequentially, eight (8) values per card, not to exceed 200 values, i.e. 25 cards.

Data Card 3

This data card consists of the array containing the values for the accept line. Data must be arranged sequentially, eight (8) values per card, not to exceed 200 values, i.e. 25 cards.

Data Card 4

Field 1	MATRIX (K, 1) (F10.2)	The maximum number of failures for the test plan.
Field 2	MATRIX (K, 2) (F10.2)	The maximum test time (THETA ONE Multiple) for the test plan.
Field 3	MATRIX (K, 3) (F10.2)	The minimum number of failures from which to reach maximum test time.

Note: For data card 4, the data cards must be arranged sequentially, i.e. the first card must begin with test plan 1, the second card must begin with test plan 2, and so on. Data must be arranged three (3) values per card, not to exceed 25 cards.

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APPENDIX II

TABLE 5. DICTIONARY OF PROGRAM VARIABLES

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APPENDIX II

TABLE 5. DICTIONARY OF PROGRAM VARIABLES

	Variable	Type	Definition
1	NOF (I)	Program/Output	The number of failures in the test plan.
2	TMTBF (I)	Program/Output	The array of true MTBFs considered.
3	D (I)	Program	An array containing the lowest and highest true MTBF. Finds utility in the Fix Scale (FIXSCA) plotting subroutine.
4	TITLE (I)	Program	The arrays containing the symbol strings for the plotting subroutines.
5	AKOUNT (I) BKOUNT (I) CKOUNT (I) DKOUNT (I)	Program " " "	Arrays used for holding values from the counters.
6	MAXNRF	Input	The maximum number of failures for the test plan.
7	NRITER	Input	The number of iterations for the simulation.
8	NRTP	Input	The number of the test plan being implemented.
9	NRPLNS	Input	The number of plans in the test plan matrix.
10	BASE	Input	The lowest MTBF in the range of MTBFs considered.
11	VALUE	Input	The highest MTBF in the range of MTBFs considered.
12	DELTAX	Input	The increment value between successive MTBFs.
13	THETA1	Input	The lower test MTBF.

APPENDIX II

TABLE 5. DICTIONARY OF PROGRAM VARIABLES (CONTINUED)

	Variable	Type	Definition
14	INTVLS	Program	The number of intervals for the accept-reject criteria.
15	NRMTBF	Program	The number of MTBFs in the range of MTBFs considered.
16	UPPER	Program	The value used for maximum test time.
17	LIMIT	Program	The minimum number of failures from which to reach maximum test time.
18	KOUNT	Program	A local counter used to store the number of times maximum test time is reached.
19	KNT	Program	A local counter used to store the number of times the last failure is reached.
20	NCASE	Program	A local counter for tracking the number of cases in the simulation.
21	ACCUM	Program	An accumulator used for storing an (exponential) time to failure.
22	NFAIL1	Program	The number of the failure being scrutinized in the simulation.
23	RLINE (I)	Input/Output	The array containing the values for the reject line.
24	ALINE (I)	Input/Output	The array containing the values for the accept line.
25	MATRIX (I)	Input/Output	An array containing the test plan matrix.

APPENDIX III

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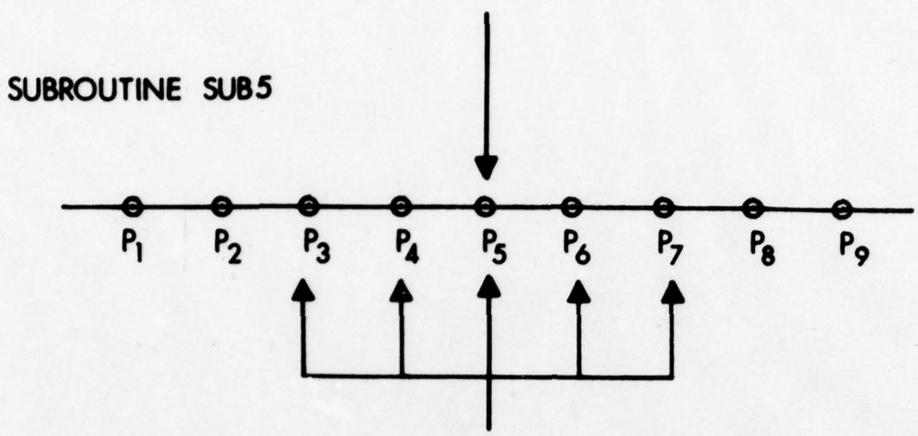

Figure 8. Curve Smoothing Scheme (5- Point)

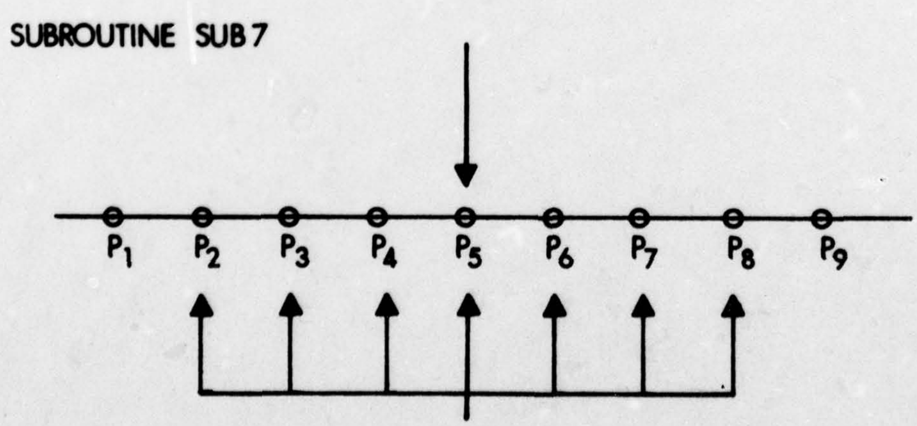

Figure 9. Curve Smoothing Scheme (7-Point)

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APPENDIX IV

FIGURE 10. PROGRAM FLOW CHART

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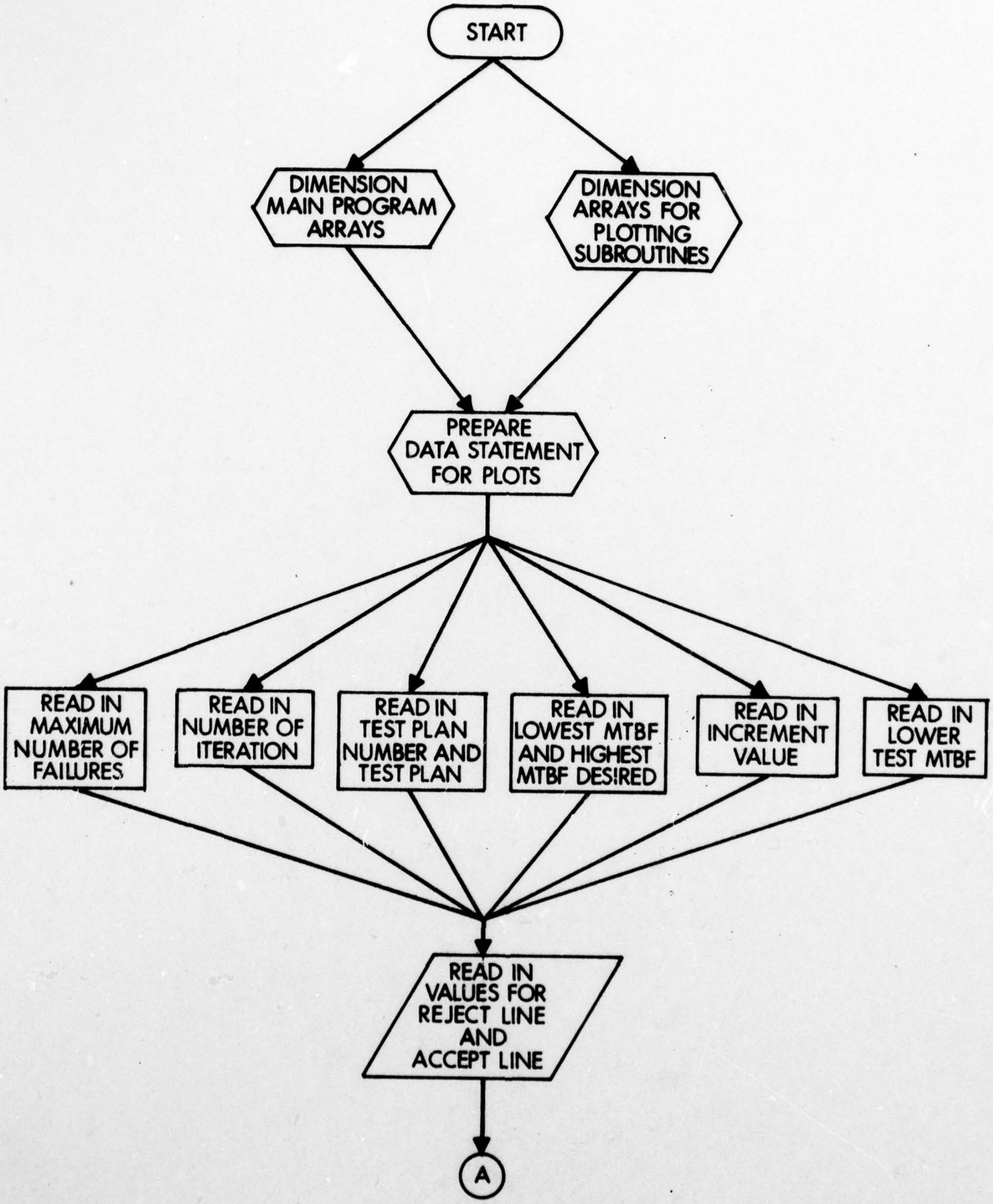
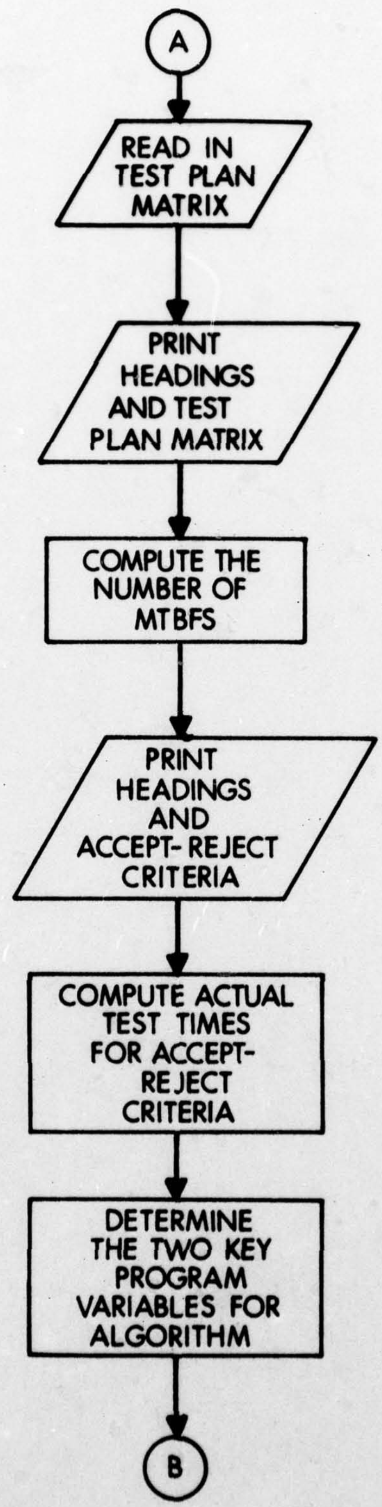
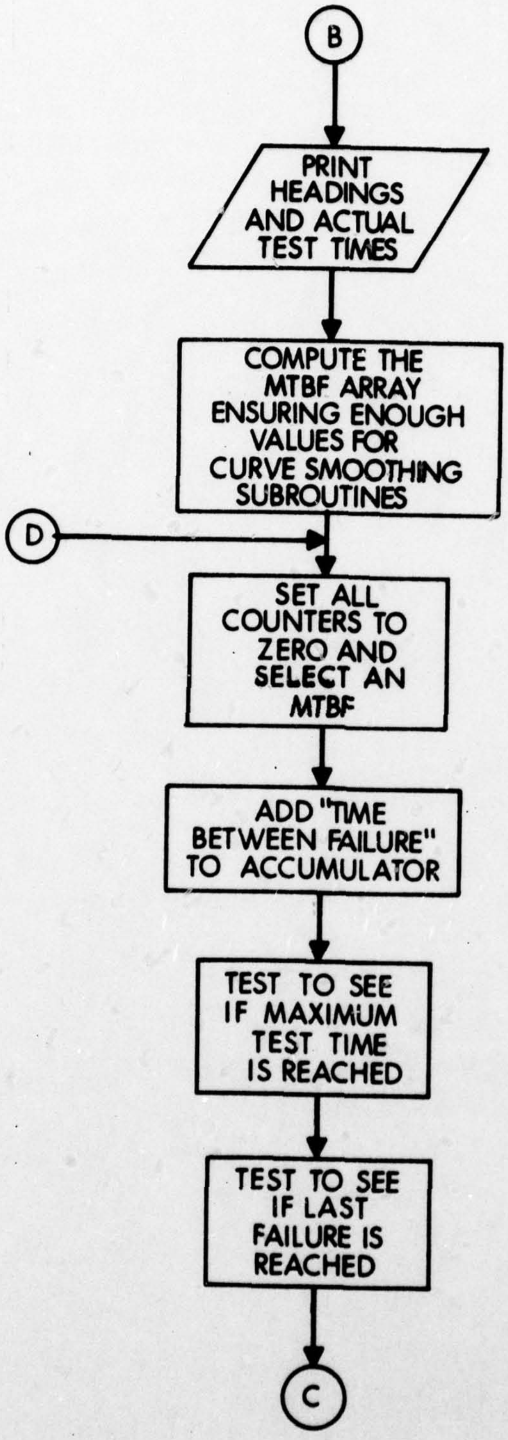
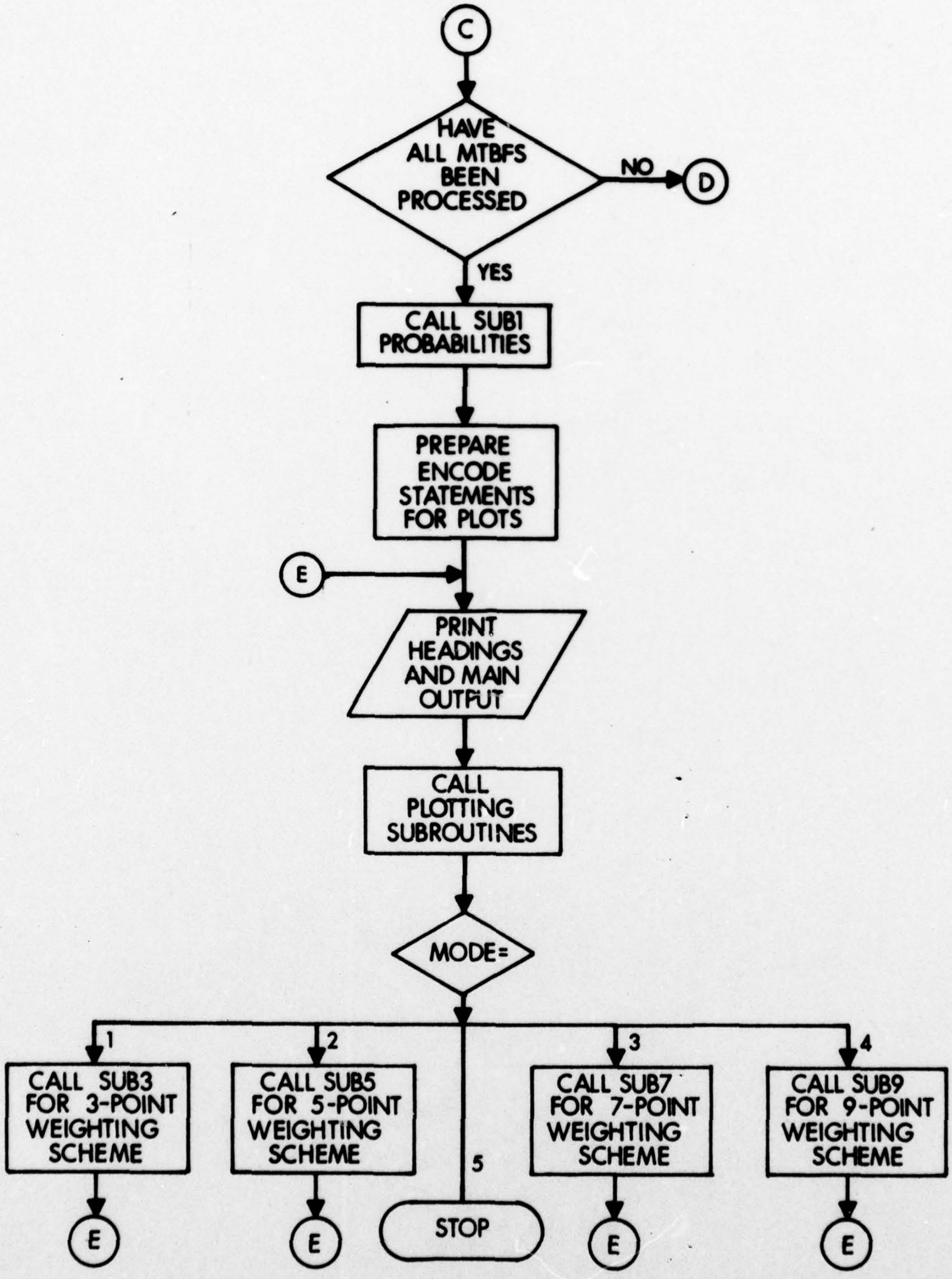


Figure 10. Program Flow Chart.


A
READ IN TEST PLAN MATRIX
PRINT HEADINGS AND TEST PLAN MATRIX
COMPUTE THE NUMBER OF MTBFS
PRINT HEADINGS AND ACCEPT-REJECT CRITERIA
COMPUTE ACTUAL TEST TIMES FOR ACCEPT-REJECT CRITERIA
DETERMINE THE TWO KEY PROGRAM VARIABLES FOR ALGORITHM
B


B
PRINT HEADINGS AND ACTUAL TEST TIMES
COMPUTE THE MTBF ARRAY ENSURING ENOUGH VALUES FOR CURVE SMOOTHING SUBROUTINES
D
SET ALL COUNTERS TO ZERO AND SELECT AN MTBF
ADD "TIME BETWEEN FAILURE" TO ACCUMULATOR
TEST TO SEE IF MAXIMUM TEST TIME IS REACHED
TEST TO SEE IF LAST FAILURE IS REACHED
C


C
HAVE ALL MTBFS BEEN PROCESSED
NO
D
YES
CALL SUB1 PROBABILITIES
PREPARE ENCODE STATEMENTS FOR PLOTS
E
PRINT HEADINGS AND MAIN OUTPUT
CALL PLOTTING SUBROUTINES
MODE=
1
2
3
4
5
CALL SUB3 FOR 3-POINT WEIGHTING SCHEME
CALL SUB5 FOR 5-POINT WEIGHTING SCHEME
CALL SUB7 FOR 7-POINT WEIGHTING SCHEME
CALL SUB9 FOR 9-POINT WEIGHTING SCHEME
STOP
E
E
E
E

APPENDIX V

SUMMARY OF RESULTS - TEST PLANS I - VIII

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APPENDIX V

SUMMARY OF RESULTS - TEST PLANS I - VIII

The following table and figures give a brief summary of results for test plans I through VIII. In each case, THETA ONE has been chosen as 100 hours MTBF. Figures Ia - VIIIa depict the probability of reaching the last failure, $P(F_L)$, while Figures Ib - VIIIb depict the probability of reaching the maximum test time , $P(T_M)$.

TABLE 6

SUMMARY OF RESULTS

Test Plan PRST	Decision Risks	Discrimination Ratio	Probability of Reaching Last Failure $P(F_L)$	Probability of Reaching Maximum Test Time $P(T_M)$
1	10%	1.5:1	.16 @ θ_1 .07 @ θ_o	.05 @ θ_1 .16 @ θ_o
2	20%	1.5:1	.12 @ θ_1 .08 @ θ_o	.12 @ θ_1 .21 @ θ_o
3	10%	2.0:1	.08 @ θ_1 .04 @ θ_o	.07 @ θ_1 .20 @ θ_o
4	20%	2.0:1	.10 @ θ_1 .07 @ θ_o	.10 @ θ_1 .28 @ 0_o
5	10%	3.0:1	.15 @ θ_1 .07 @ θ_o	.07 @ θ_1 .37 @ θ_o
6	20%	3.0:1	.86 @ θ_1 .38 @ θ_o	.13 @ θ_1 .39 @ θ_o
7	30%	1.5:1	.44 @ θ_1 .33 @ θ_o	.26 @ θ_1 .52 @ θ_o
8	30%	2.0:1	.80 @ θ_1 .49 @ θ_o	.09 @ θ_1 .26 @ θ_o

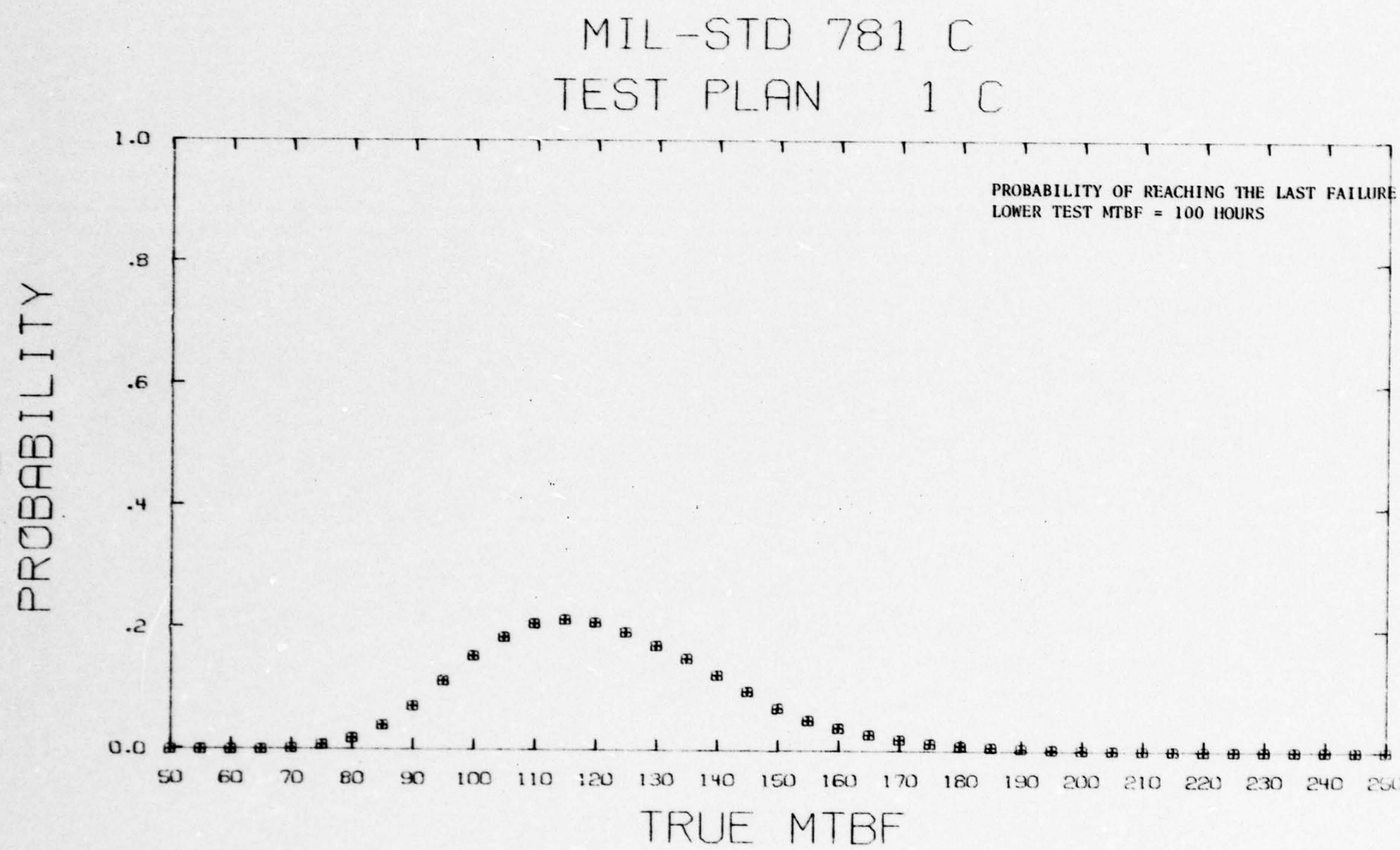

MIL-STD 781 C
TEST PLAN 1 C
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
TRUE MTBF

FIGURE 1A

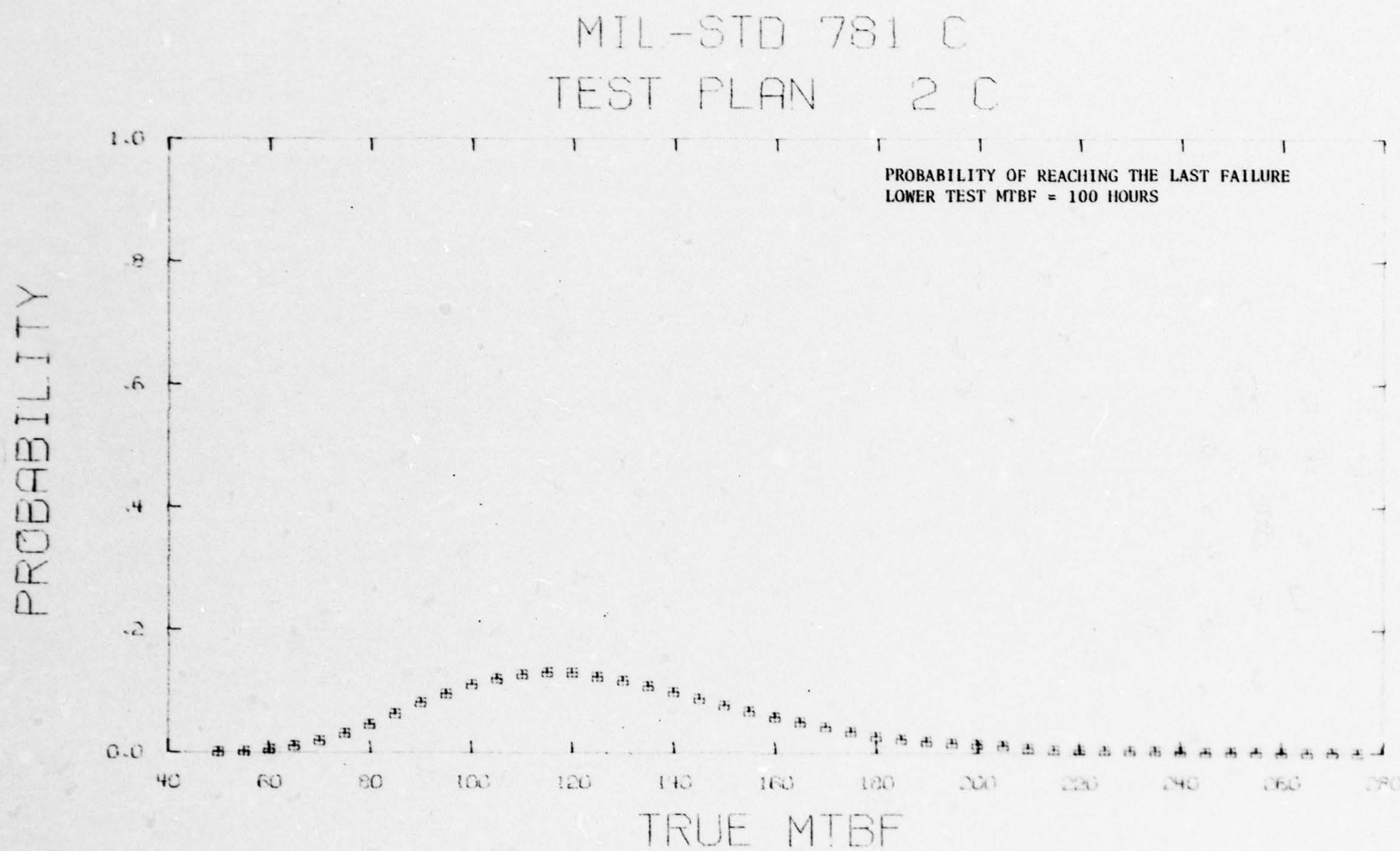

MIL-STD 781 C
TEST PLAN 2 C
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
40
60
80
100
120
140
160
180
200
220
240
260
280
TRUE MTBF

FIGURE 2A

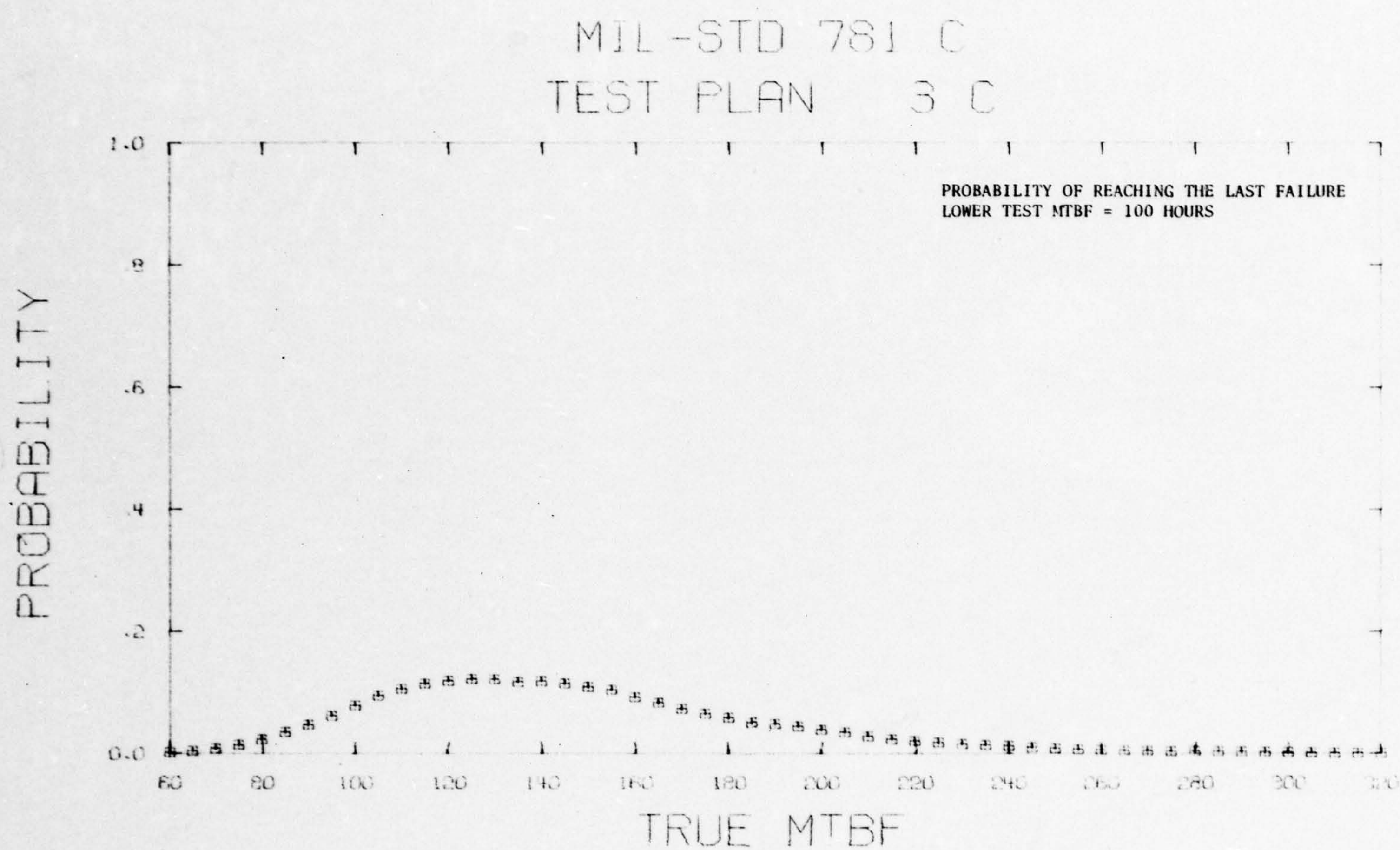
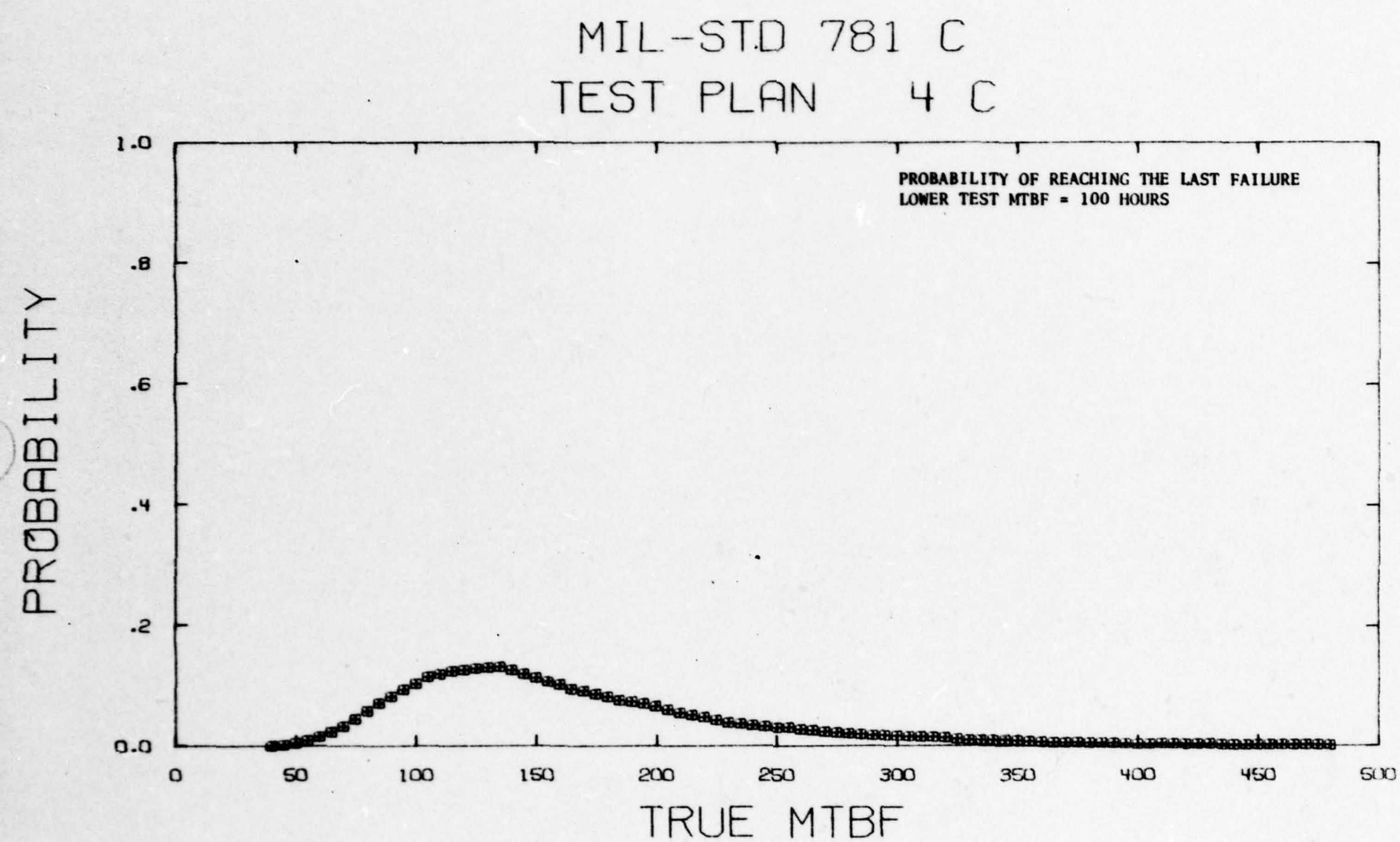

MIL-STD 781 C
TEST PLAN 3 C
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
60
80
100
120
140
160
180
200
220
240
260
280
300
320
TRUE MTBF

FIGURE 3A



MIL-STD 781 C
TEST PLAN 4 C
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
TRUE MTBF

FIGURE 4A

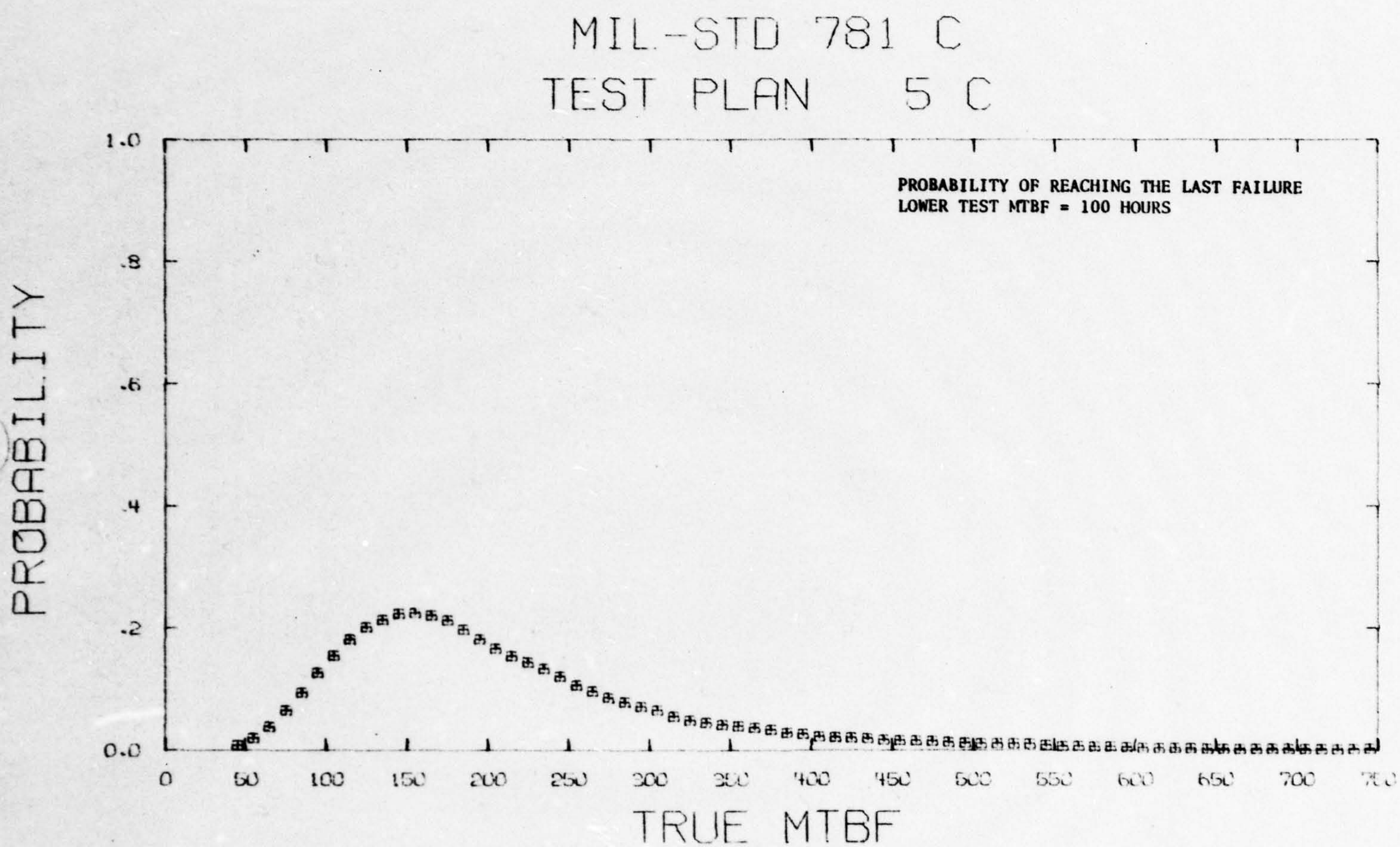

MIL-STD 781 C
TEST PLAN 5 C
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
TRUE MTBF

FIGURE 5A

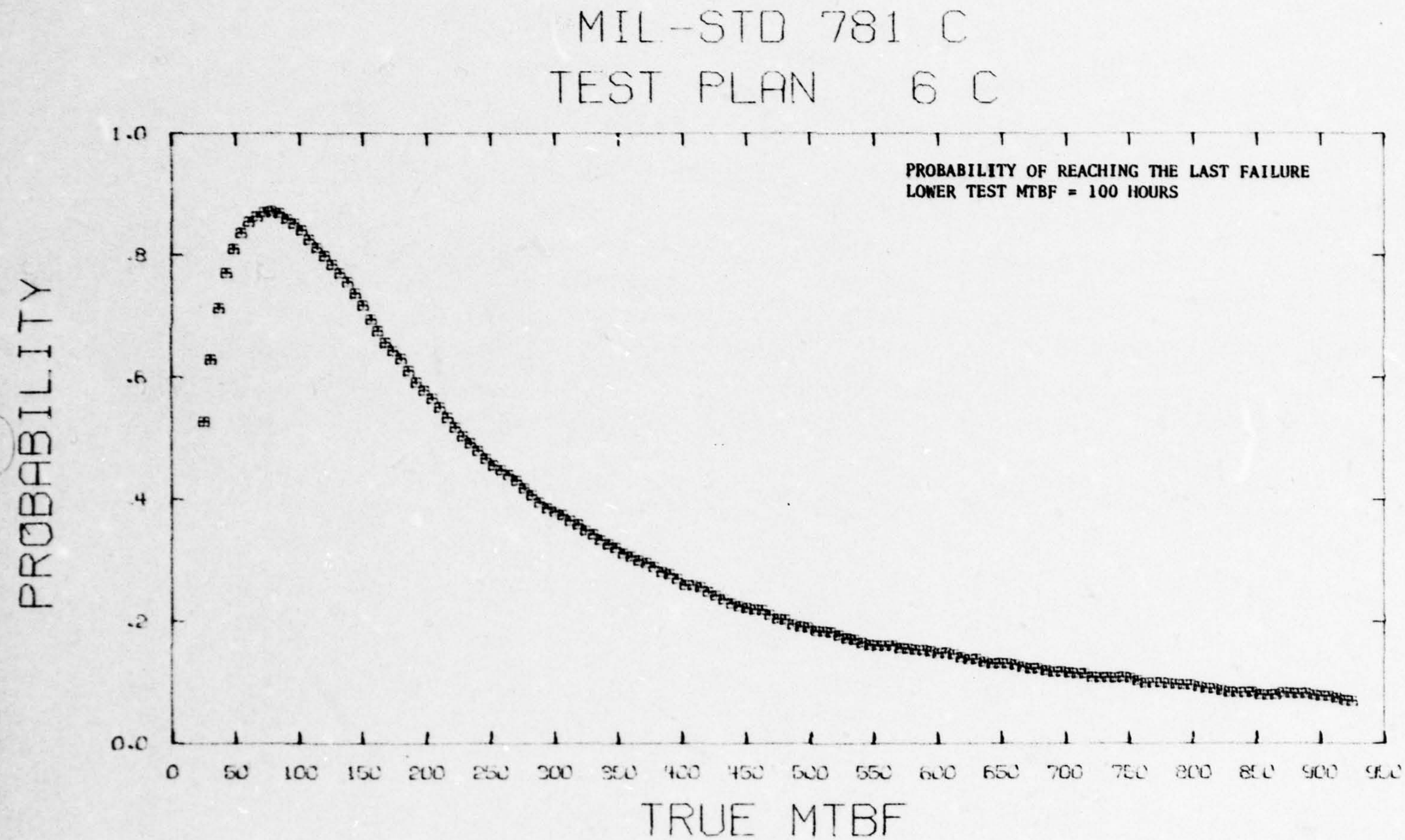
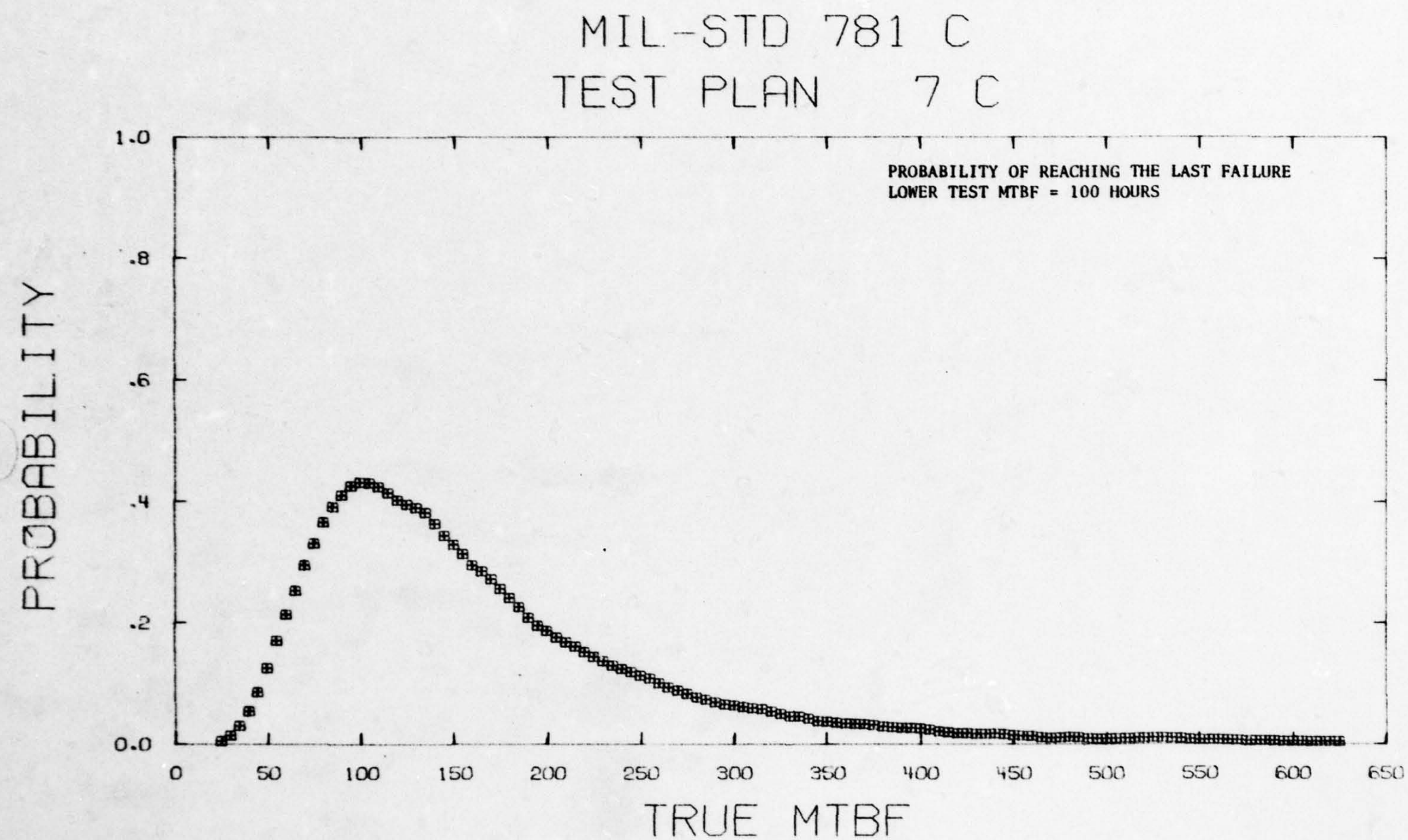

MIL-STD 781 C
TEST PLAN 6 C
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
TRUE MTBF

FIGURE 6A



MIL-STD 781 C
TEST PLAN 7 C
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
TRUE MTBF

FIGURE 7A

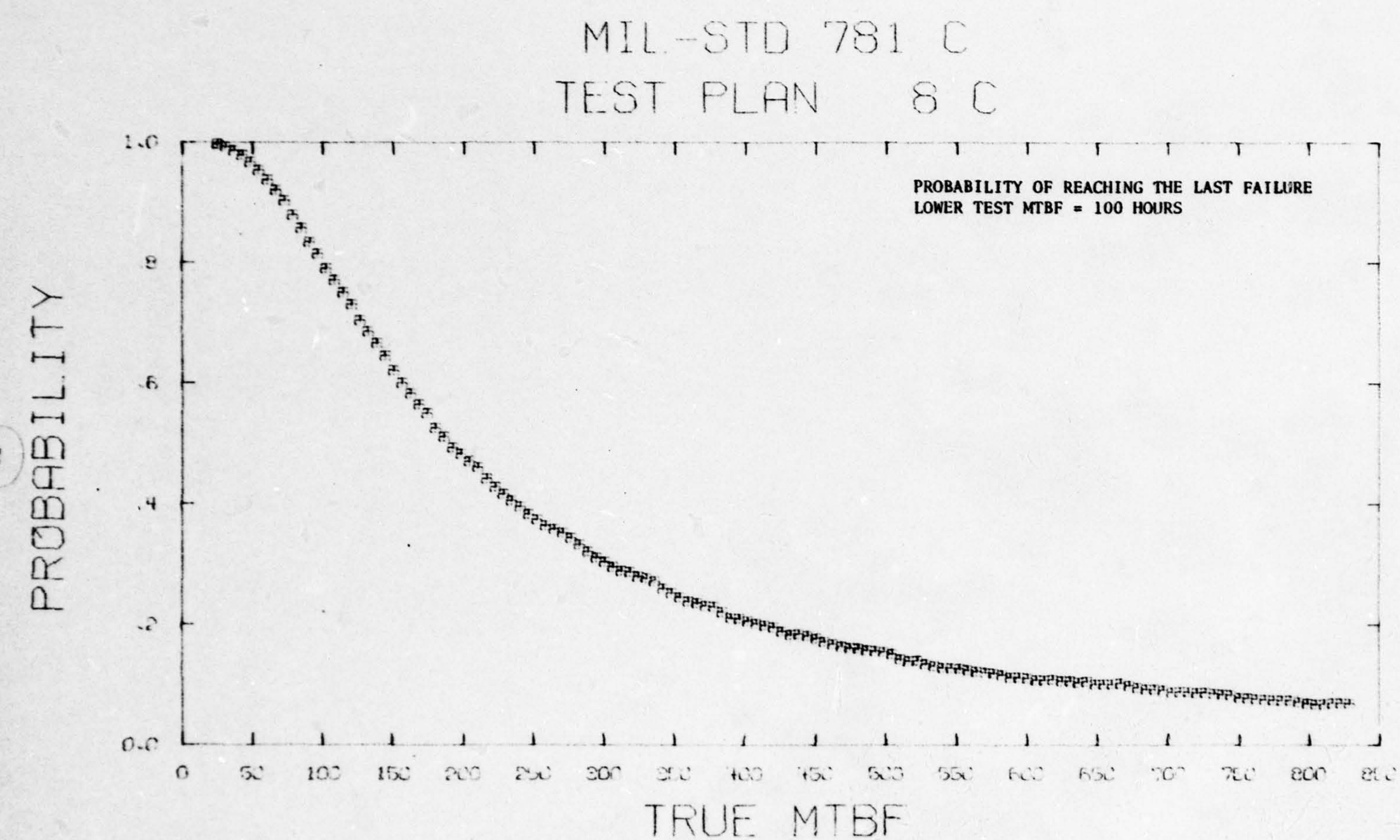

MIL-STD 781 C
TEST PLAN 8 C
PROBABILITY OF REACHING THE LAST FAILURE
LOWER TEST MTBF = 100 HOURS
PROBABILITY
TRUE MTBF

FIGURE 8A

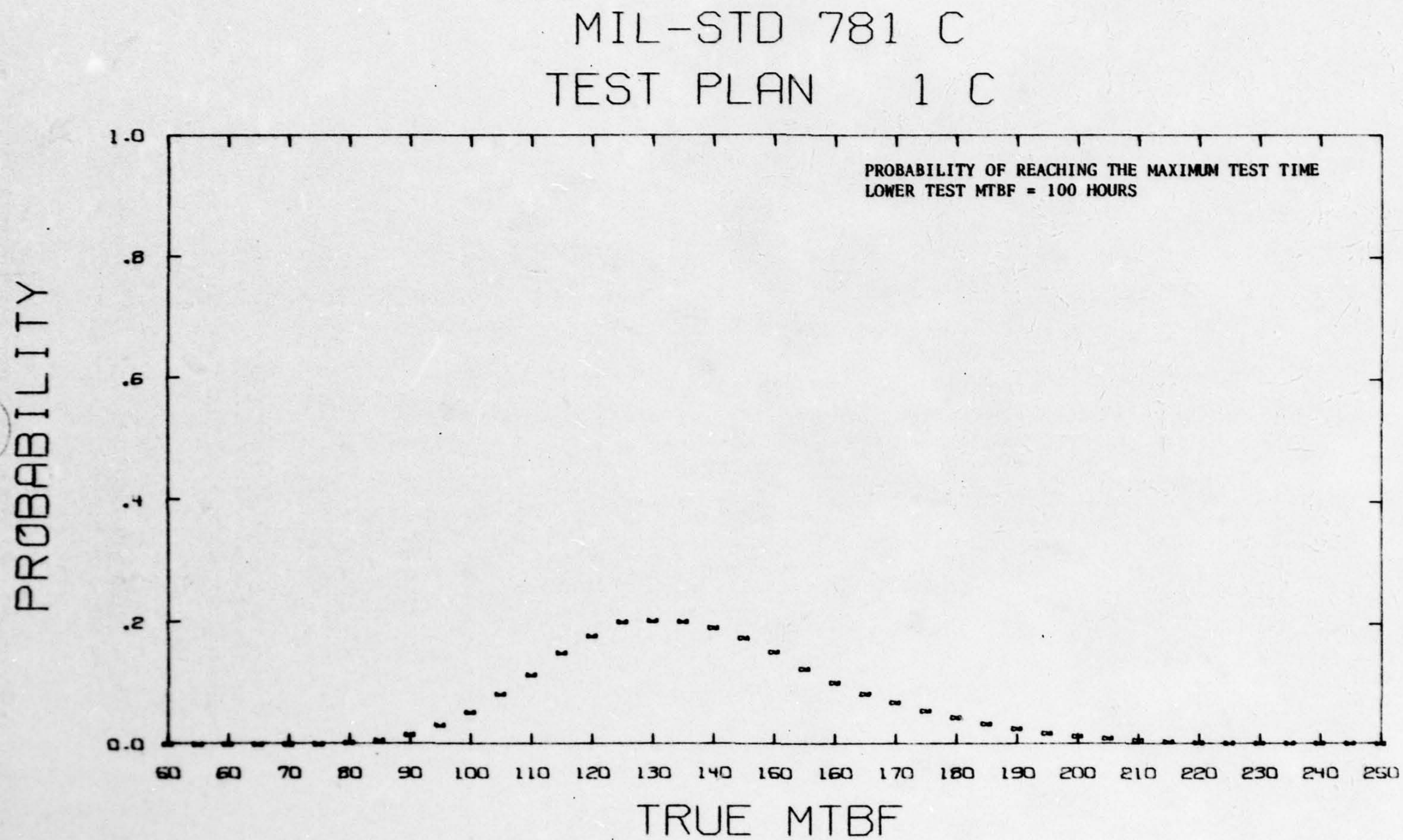

MIL-STD 781 C
TEST PLAN 1 C
PROBABILITY OF REACHING THE MAXIMUM TEST TIME
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
TRUE MTBF

FIGURE 1B

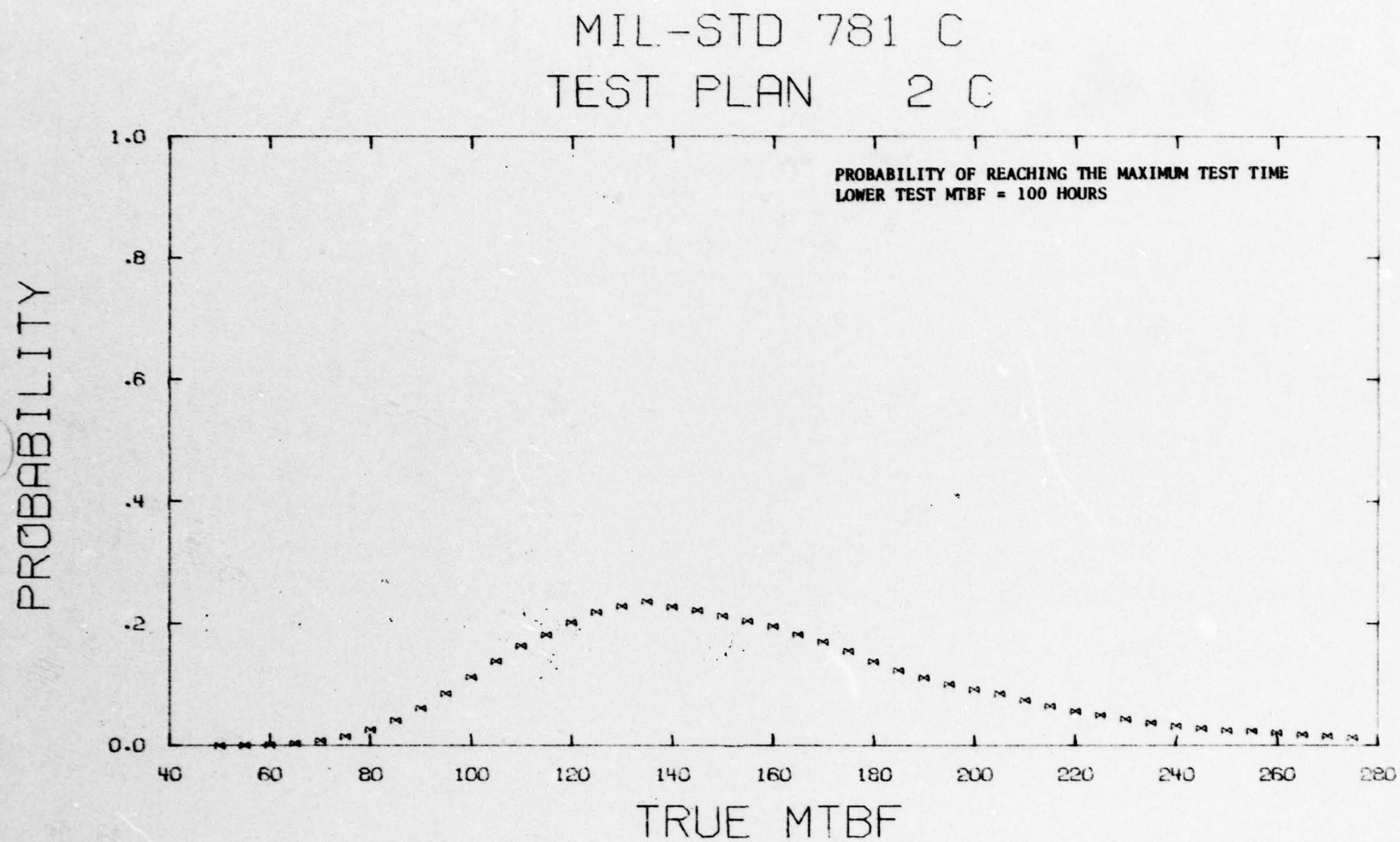

MIL-STD 781 C
TEST PLAN 2 C
PROBABILITY OF REACHING THE MAXIMUM TEST TIME
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
40
60
80
100
120
140
160
180
200
220
240
260
280
TRUE MTBF

FIGURE 2B

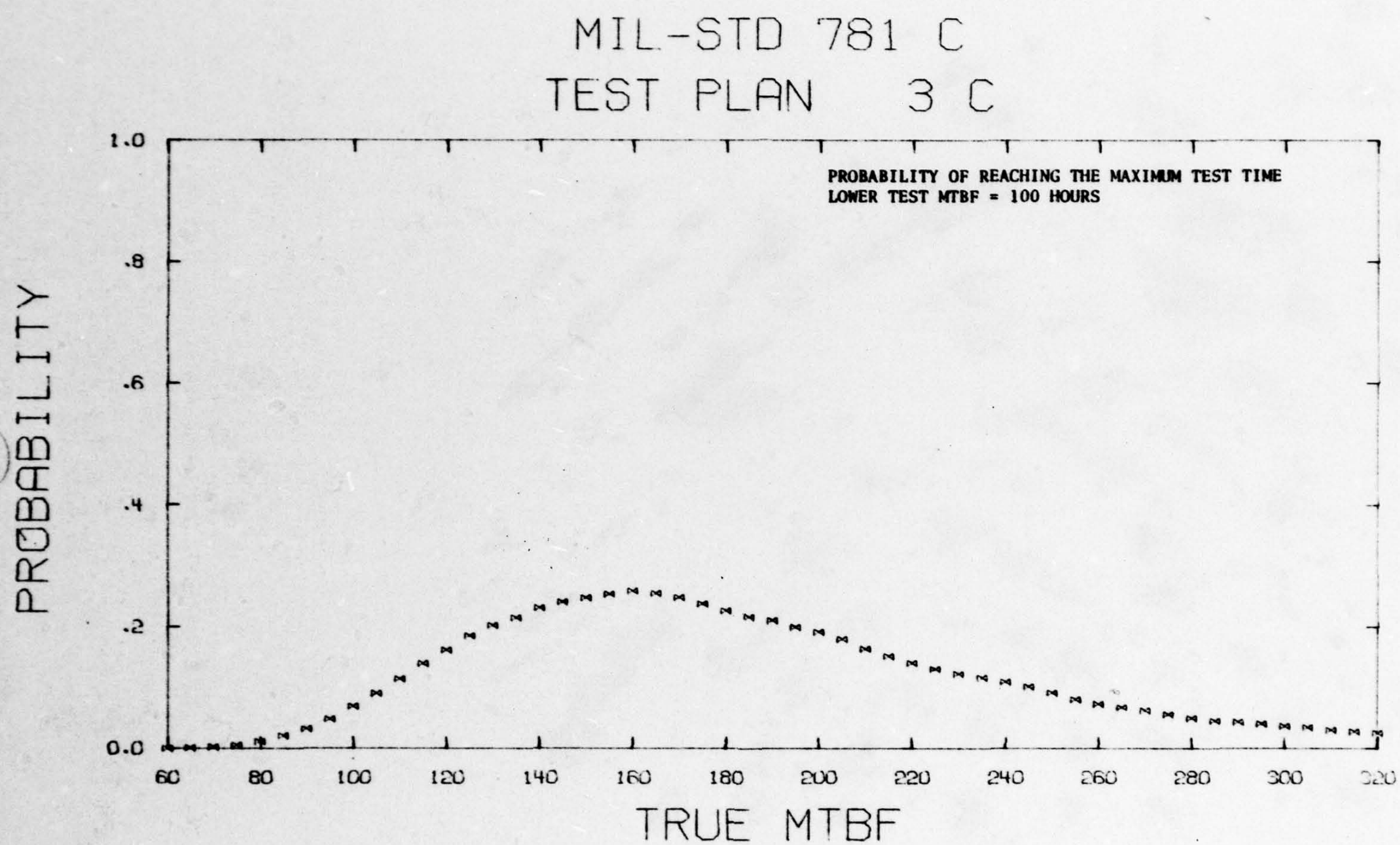

MIL-STD 781 C
TEST PLAN 3 C
PROBABILITY OF REACHING THE MAXIMUM TEST TIME
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
60
80
100
120
140
160
180
200
220
240
260
280
300
320
TRUE MTBF

FIGURE 3B

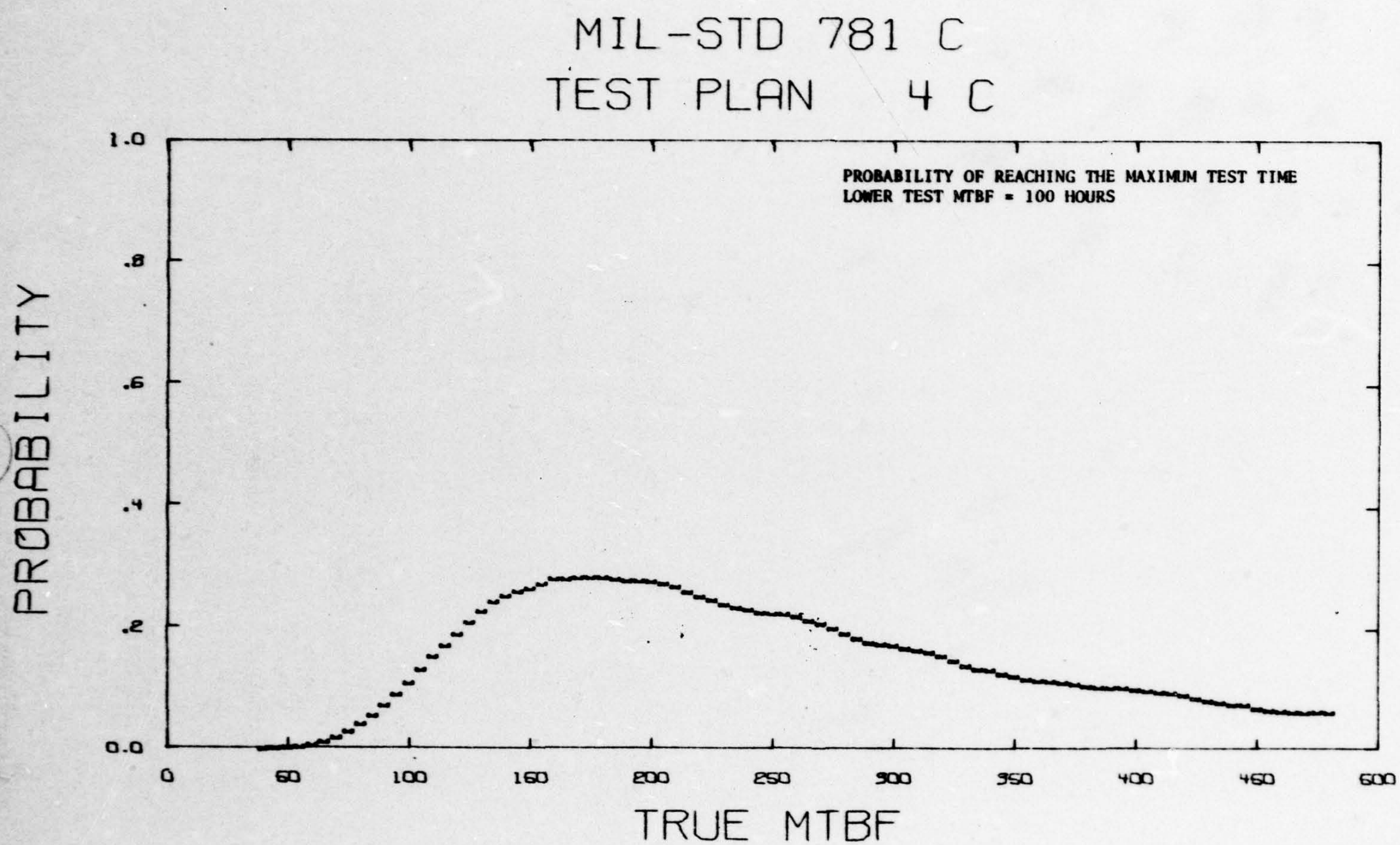

MIL-STD 781 C
TEST PLAN 4 C
PROBABILITY OF REACHING THE MAXIMUM TEST TIME
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
TRUE MTBF

FIGURE 4B

MIL-STD 781 C

TEST PLAN 5 C

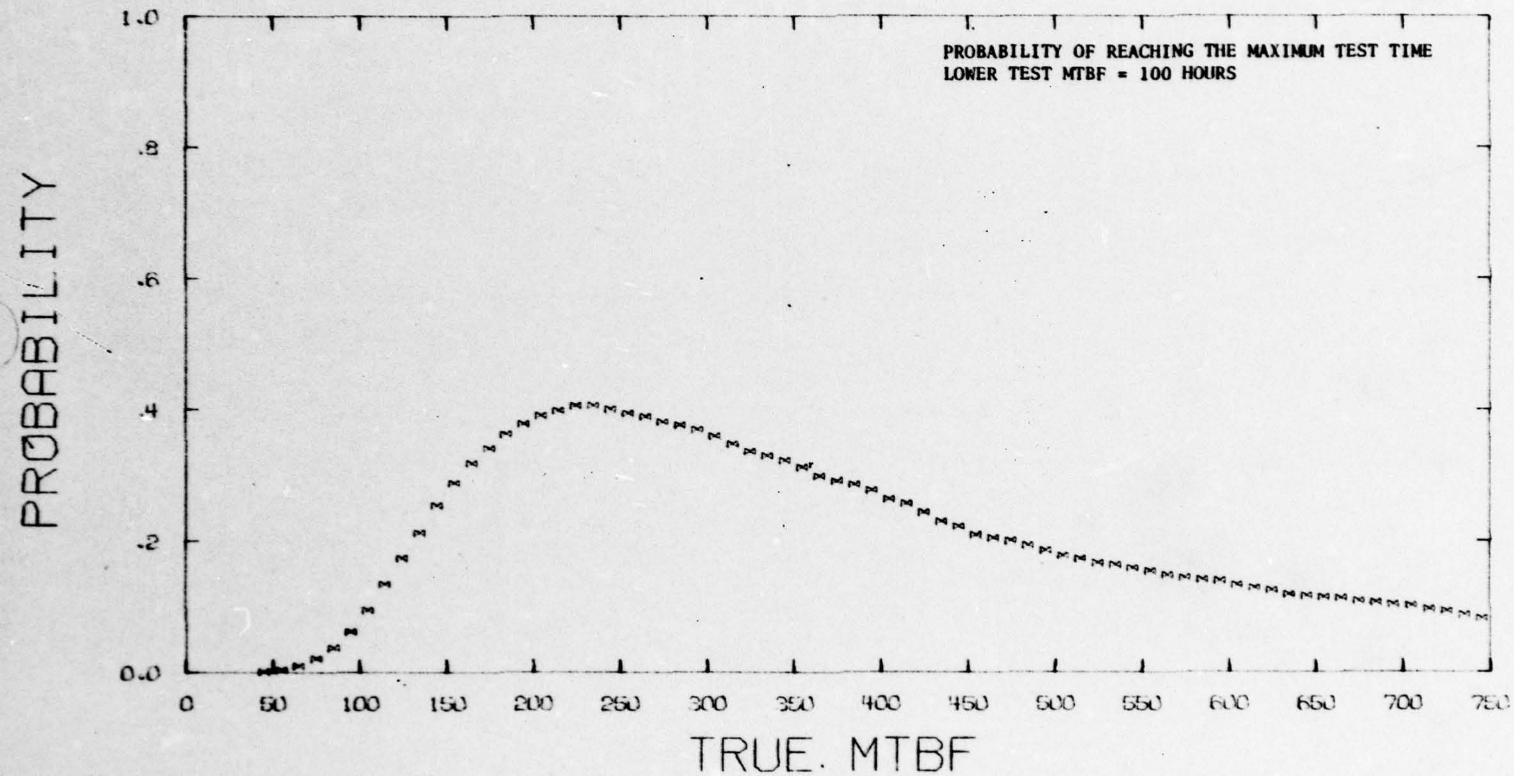


FIGURE 5B

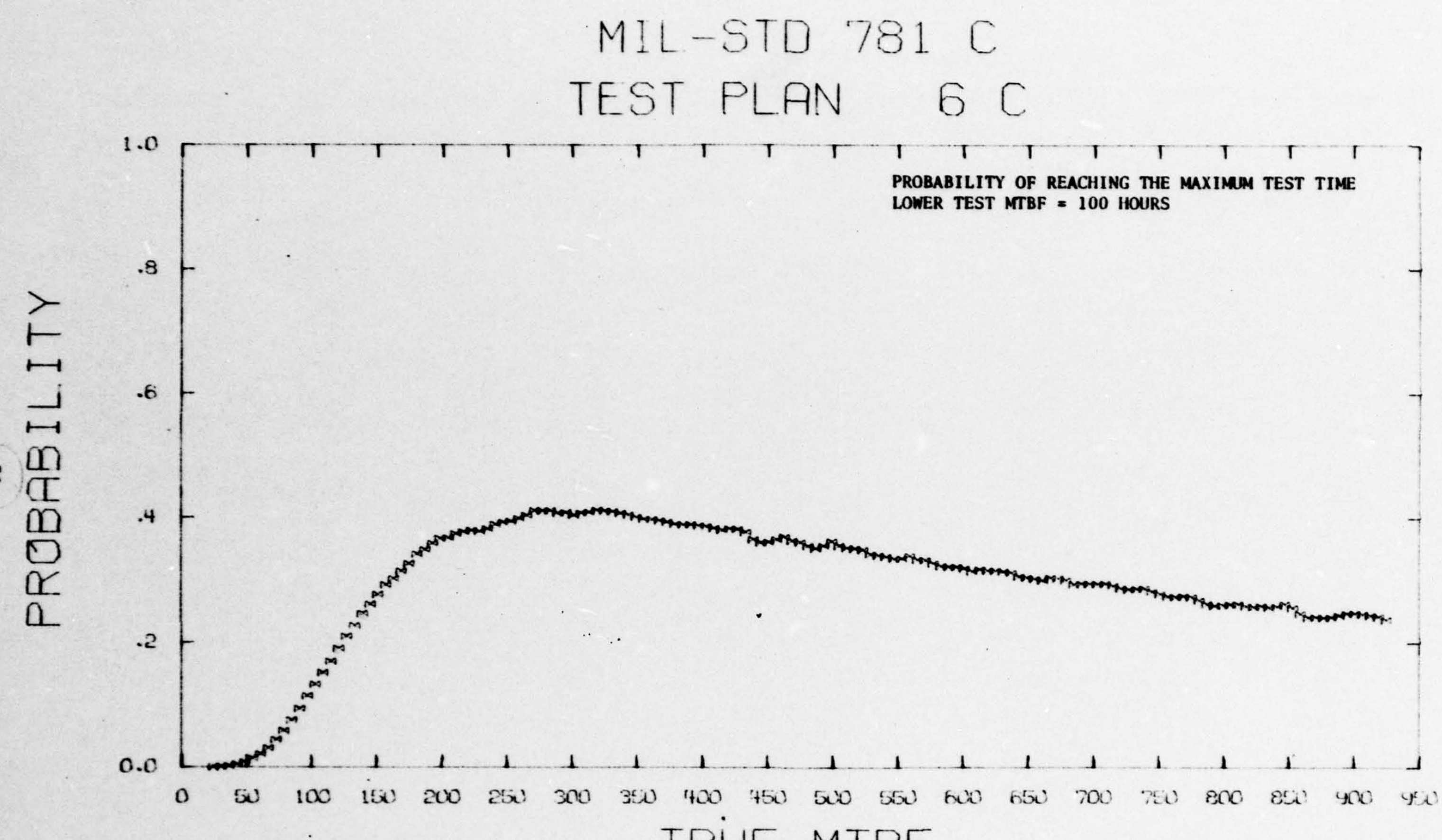

MIL-STD 781 C
TEST PLAN 6 C
PROBABILITY OF REACHING THE MAXIMUM TEST TIME
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
TRUE MTBF

FIGURE 6B

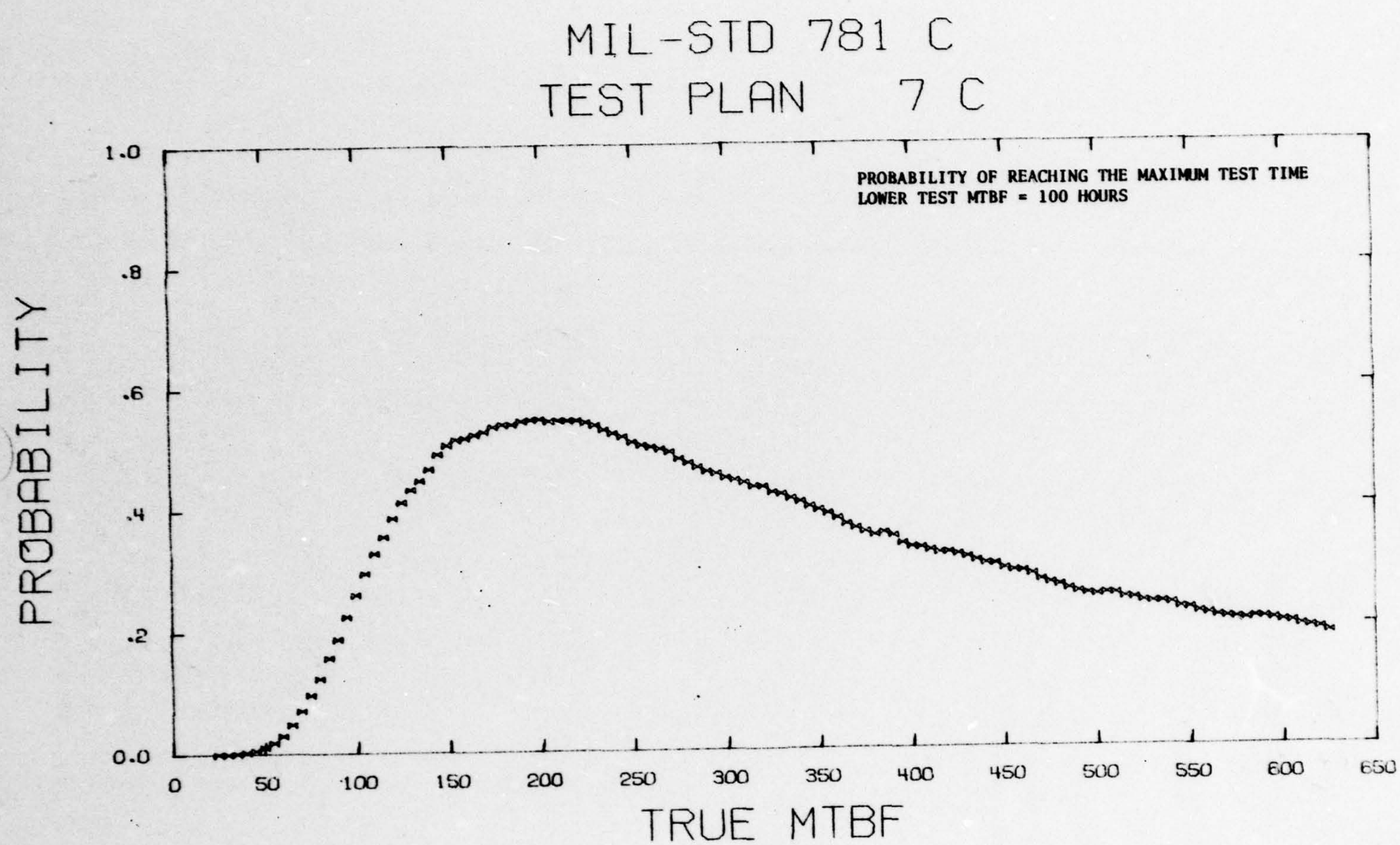
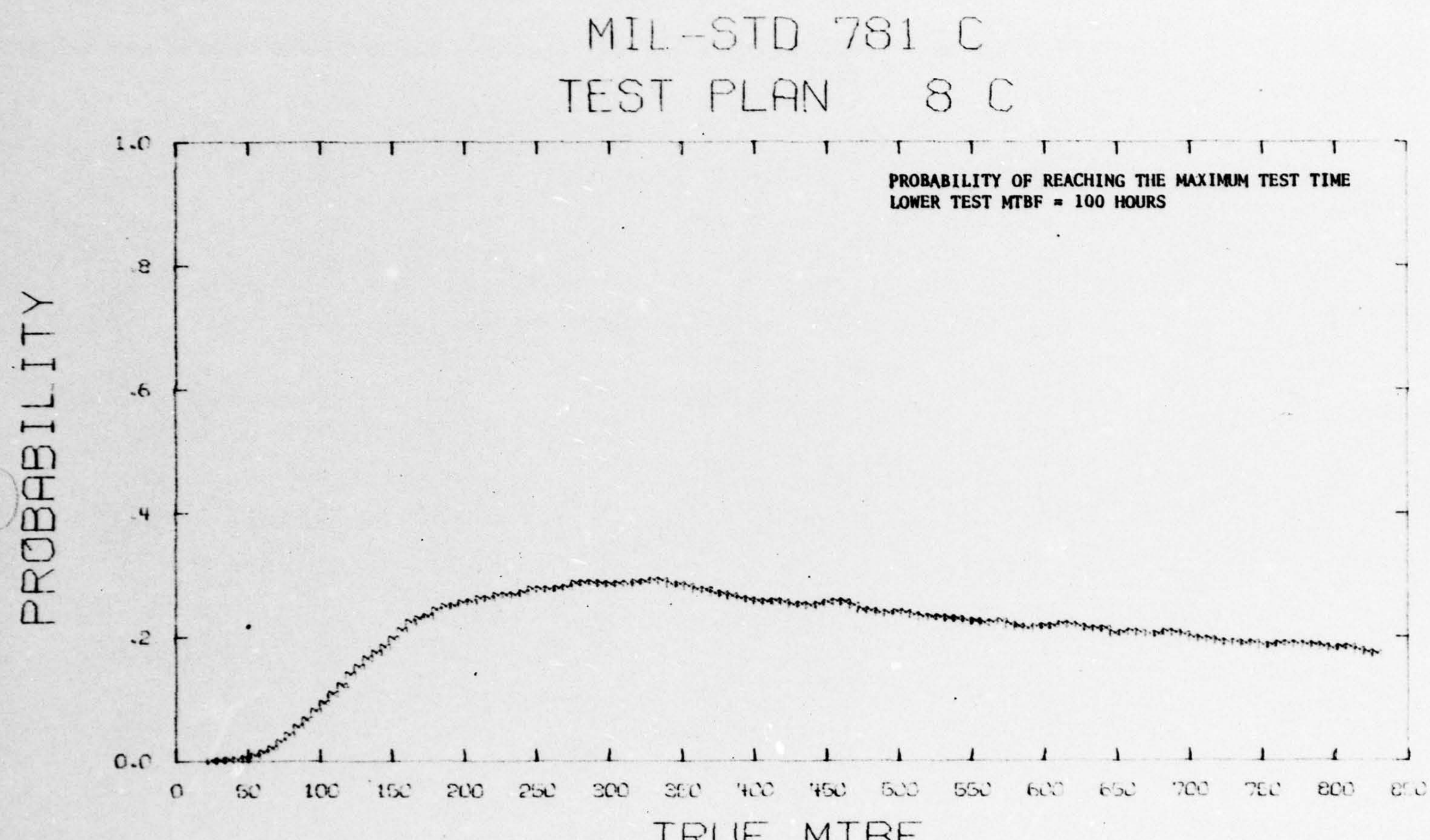

MIL-STD 781 C
TEST PLAN 7 C
PROBABILITY OF REACHING THE MAXIMUM TEST TIME
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
TRUE MTBF

FIGURE 7B



MIL-STD 781 C
TEST PLAN 8 C
PROBABILITY OF REACHING THE MAXIMUM TEST TIME
LOWER TEST MTBF = 100 HOURS
PROBABILITY
1.0
.8
.6
.4
.2
0.0
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
TRUE MTBF

FIGURE 8B

```
RILLY.T90.STMFZ.P2.
ACCOUNT(SAIREL)
BEGIN.ATTACH.PLOTLIB.
REQUEST.TAPE13.*PF.
FTN(GO.SL.RL.R)
MAP(PART)
BEGIN.PLOT.CALCOMP.TAPE13.
EXIT.
BEGIN.PLOT.CALCOMP.TAPE13.
EXIT.
?
      PROGRAM  MS781C(INPUT.OUTPUT.TAPE5=INPUT.TAPE6=OUTPUT.TAPE13)
C          THIS PROGRAM IS A MONTE CARLO SIMULATION OF A PROBABILITY
C               RATIO SEQUENTIAL TEST (PRST) PLAN FROM MILITARY
C               STANDARD 781C.  THIS SIMULATION DETERMINES. FOR A
C               RANGE OF TRUE MTBFS. (1) THE PROBABILITY OF REACHING
C               MAXIMUM (TOTAL) TEST TIME BEFORE MAKING A DECISION
C               (EITHER ACCEPT OR REJECT) AND (2) THE PROBABILITY
C               OF REACHING THE LAST FAILURE.  FOUR SUBROUTINES ARE
C               INTRODUCED INTO THE PROGRAM FOR THE EXPRESS PURPOSE
C               OF PERFORMING CURVE SMOOTHING.  THIS PROCEDURE IS
C               ACCOMPLISHED WITH THE AID OF FOUR DIFFERENT WEIGHTING
C               SCHEMES. UTILIZING (1) A NEIGHBORHOOD OF THREE POINTS.
C               (2) A NEIGHBORHOOD OF FIVE POINTS. (3) A NEIGHBORHOOD
C               OF SEVEN POINTS. AND (4) A NEIGHBORHOOD OF NINE POINTS.
      INTEGER         NOF(200)
      REAL            RLINE(200).ALINE(200)
      REAL            TMTBF(500).MTBF(500)
      REAL            MATRIX(25.3).D(2)
      REAL            TITLE1(1).TITLE2(2)
      REAL            TITLE3(2).TITLE4(2)
      REAL            TITLE5(5).TITLE6(6)
      DIMENSION       TITLE7(4).LABEL(4)
      COMMON          AKOUNT(500).BKOUNT(500)
      COMMON          CKOUNT(500).DKOUNT(500)
      DATA            LABEL/'BROEMM'.'SAIREL'.'B367'.'X3588'/
      DATA            NOPLOT/0/
      READ(5.10)MAXNBF.NHITER.NHTP.NRPLNS.BASE.VALUE.DELTAX.THETA1
   10 FORMAT(4I10.4F10.2)
      INTVLS=MAXNBF+1
      READ(5.20)(RLINE(I).I=1.INTVLS)
   20 FORMAT(8F10.2)
      READ(5.20)(ALINE(I).I=1.INTVLS)
      DO 30 K=1.INTVLS
      NOF(K)=K-1
   30 CONTINUE
      DO 50 K=1.NRPLNS
      READ(5.40)MATRIX(K.1).MATRIX(K.2).MATRIX(K.3)
   40 FORMAT(3F10.2)
   50 CONTINUE
      WRITE(6.60)
   60 FORMAT('1'.T38.'MILITARY STANDARD  781 C'//T78.
     $'THE MINIMUM NUMBER'/T79.'OF FAILURES FROM'/T4.
     $'TEST  PLAN'.T24.'MAXIMUM NUMBER'.T49.
     $'MAXIMUM  TEST TIME'.T80.'WHICH TO REACH'/T6.
     $'NUMBER'.T25.'OF  FAILURES'.T48.'(THETA ONE '.T59.
     $'MULTIPLE)'.T79.'MAXIMUM TEST TIME'/T4.
     $10('-').T24.14('-').T48.20('-').T78.18('-'))
      WRITE(6.70)(L.MATRIX(L.1).MATRIX(L.2).MATRIX(L.3).L=1.NRPLNS)
   70 FORMAT('0'.T7.I3.T29.F5.0.T53.F10.2.T85.F5.0)
      RNMTBF=(VALUE-BASE)/DELTAX+1.
      IF(RNMTBF.GT.AINT(RNMTBF))GOTO 80
      NMTBF=RNMTBF
      GOTO 90
```

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```
 80 NRMTHF=NRMTHF+1.0
 90 WRITE(6.100)
100 FORMAT('1'.T4.'MILITARY STANDARD 781 C')
    WRITE(6.110)NRTP
110 FORMAT('0'.T4.'TEST PLAN '.I3)
    WRITE(6.120)MAXNRF
120 FORMAT('0'.T4.'THE MAXIMUM NUMBER OF FAILURES '.
   $'FOR THIS PLAN IS  '.I4///)
    WRITE(6.130)
130 FORMAT(' '.T22.'ACCEPT-REJECT CRITERIA'/T22.
   $22('-'))
    WRITE(6.140)
140 FORMAT('0'.T34.'TOTAL TEST TIME')
    WRITE(6.150)
150 FORMAT(' '.T31.'(THETA ONE  MULTIPLE)')
    WRITE(6.160)
160 FORMAT('0'.T8.'NUMBER  OF'/T9.'FAILURES'.T26.
   $'REJECT  LINE'.T46.'ACCEPT  LINE'/T8.
   $10('-').T26.12('-').T46.12('-'))
    DO 190 K=1.INTVLS
    IF(MOD(K.20).EQ.0)WRITE(6.170)
    WRITE(6.180)NOF(K).RLINE(K).ALINE(K)
170 FORMAT('1'.T8.'NUMBER  OF'/T9.'FAILURES'.T26.
   $'REJECT  LINE'.T46.'ACCEPT  LINE'/T8.
   $10('-').T26.12('-').T46.12('-'))
180 FORMAT('0'.T11.I4.T27.F10.2.T47.F10.2)
190 CONTINUE
    DO 200 K=1.INTVLS
    RLINE(K)=RLINE(K)*THETA1
    ALINE(K)=ALINE(K)*THETA1
200 CONTINUE
    DO 210 L=1.NRPLNS
    MATRIX(L.2)=MATRIX(L.2)*THETA1
210 CONTINUE
    DO 220 K=1.NRPLNS
    IF(MAXNRF.EQ.IFIX(MATRIX(K.1)))UPPER=MATRIX(K.2)
    IF(MAXNRF.EQ.IFIX(MATRIX(K.1)))LIMIT=MATRIX(K.3)
220 CONTINUE
    WRITE(6.100)
    WRITE(6.110)NRTP
    WRITE(6.230)THETA1
230 FORMAT('0'.T4.'THETA ONE FOR THIS PLAN IS  '.
   $T32.F10.2.T44.'HOURS')
    WRITE(6.240)UPPER
240 FORMAT('0'.T4.'THE MAXIMUM TEST TIME FOR THIS '.
   $'PLAN IS  '.F10.2.T56.'HOURS')
    WRITE(6.250)BASE.VALUE
250 FORMAT('0'.T4.'THE RANGE OF TRUE MTBFS CONSIDERED '.
   $'IS  '.F10.2.' - '.F10.2.T68.'HOURS')
    WRITE(6.260)NRITER
260 FORMAT('0'.T4.'THE NUMBER OF ITERATIONS FOR THIS '.
   $'SIMULATION IS '.I10)
    WRITE(6.120)MAXNRF
    WRITE(6.130)
    WRITE(6.140)
    WRITE(6.160)
    DO 270 K=1.INTVLS
    IF(MOD(K.16).EQ.0)WRITE(6.170)
    WRITE(6.180)NOF(K).RLINE(K).ALINE(K)
270 CONTINUE
    BASE=BASE-4.*DELTAX
    IF(BASE.LE.0.)GOTO 540
    NUMB=NRMTHF+8
    DO 280 K=1.NUMB
    TMTHF(K)=BASE
    BASE=BASE+DELTAX
```

```
280 CONTINUE
    K=0
290 K=K+1
    NCASE=0
    ARG=1./TMTBF(K)
    KOUNT=0
    KNT=0
300 NCASE=NCASE+1
    IF(NCASE.GT.NRITER)GOTO 360
    ACCUM=0.
    DO 340 NFAIL=1,INTVLS
    NFAIL1=NFAIL-1
    IF(NFAIL1.EQ.1)GOTO 320
310 ACCUM=ACCUM+EXPRN(ARG)
    IF(ACCUM.EQ.0.)GOTO 310
    IF(NFAIL1.EQ.0.AND.ACCUM.GE.ALINE(NFAIL))GOTO 350
    IF(NFAIL1.EQ.0.AND.(ACCUM.GT.RLINE(NFAIL).AND.
   $ACCUM.LT.ALINE(NFAIL)))GOTO 340
320 DO 330 J=LIMIT,MAXNRF
    IF(NFAIL1.EQ.J.AND.ACCUM.GE.UPPER)KOUNT=KOUNT+1
330 CONTINUE
    IF(NFAIL1.EQ.MAXNRF)KNT=KNT+1
    IF(ACCUM.LE.RLINE(NFAIL).OR.ACCUM.GE.ALINE(NFAIL))GOTO 350
340 CONTINUE
350 GOTO 300
360 AKOUNT(K)=KOUNT
    RKOUNT(K)=KNT
    IF(K.NE.NUMR)GOTO 290
    TITLE1(1)='TRUE MTBF>'
    TITLE2(1)='PROBABILIT'
    TITLE2(2)='Y>'
    TITLE4(1)='MIL-STD 78'
    TITLE4(2)='1 C>'
    CALL SUM1(NRITER,NRMTBF)
    MODE=0
    LEVELS=NRMTBF/15
    IF(MOD(NRMTBF,15).GT.0)LEVELS=LEVELS+1
    IF(LEVELS.LE.0)LEVELS=1
    ENCODE(16,370,TITLE3)NRTP
370 FORMAT(10HTEST PLAN ,I3,3H C>)
    ENCODE(48,380,TITLE5)MAXNRF
380 FORMAT(42HPROBABILITY OF REACHING THE LAST FAILURE (,I4,2H)>)
    ENCODE(59,390,TITLE6)UPPER
390 FORMAT(43HPROBABILITY OF REACHING MAXIMUM TEST TIME (,F10.2,
   $6H HRS)>)
    ENCODE(35,400,TITLE7)THETA1
400 FORMAT(18HLOWER TEST MTBF = ,F10.2,7H HOURS>)
    D(1)=TMTBF(5)*1.0001
    D(2)=TMTBF(NRMTBF+4)*.99999
    DO 410 N=1,NRMTBF
    MTBF(N)=TMTBF(N+4)
410 CONTINUE
    XA=3.
420 JUMP=1
    INTO=15
    DO 470 M=1,LEVELS
    WRITE(6,430)NRTP,THETA1
430 FORMAT('1',T55,'MIL-STD 781 C'/T54,
   $'TEST PLAN  ',I3,'C'/T47,'THETA ONE = ',
   $F10.2,' HOURS'///)
    WRITE(6,440)UPPER,MAXNRF
440 FORMAT(' ',T48,'PROBABILITY OF REACHING',T77,
   $'PROBABILITY OF REACHING'/T30,'TRUE    MTBF',T51,
   $'MAXIMUM TEST TIME',T80,'THE LAST FAILURE'/T32,
   $'(HOURS)',T50,'(',F10.2,T63,'HOURS)',T79,
   $'(FAILURE NR. ',I4,')'/T30,11('-'),T48,23('-'),T77,
```

```
     $23('-'))
      DO 460 N=JUMP,INTO
      IF(N.GT.NRMTHF)GOTO 470
      JMTHF=N+4
      WRITE(6,450)TMTHF(JMTHF),CKOUNT(N),DKOUNT(N)
450   FORMAT('0',T31,F10.2,T57,F6.4,T86,F6.4)
460   CONTINUE
      JUMP=JUMP+15
      INTO=INTO+15
470   CONTINUE
      IF(NOPLOT.EQ.1)GOTO 490
      IF(MODE.GT.0)GOTO 480
      CALL   PLTBEG(72.,25.,1.0,13,LABEL)
      CALL   FIXSCA(D(1),2,10.,DS,DMIN,DMAX,DELD)
480   CALL   PLTSCA(XX,2.,DMIN,0.,DS,.2)
      CALL   PLTDTS(3,10,MTBF,CKOUNT,NRMTHF,0)
      CALL   PLTAXS(DELD,.2,DMIN,DMAX,0.0,1.0,4)
      CALL   LABELA(DELD,.2,DMIN,DMAX,0.,1.,1.,1.)
      CALL   PLTSCA(XX,2.,0.,0.,DS,.2)
      CALL   PLTDTS(3,10,2.05*DS,1.45,1,0)
      CALL   PLTDTS(3,14,2.05*DS,1.55,1,0)
      CALL   PLTSYM(.25,TITLE1,0.,3.875*DS,-.15)
      CALL   PLTSYM(.25,TITLE2,90.,-DS,.225)
      CALL   PLTSYM(.25,TITLE3,0.,3.125*DS,1.05)
      CALL   PLTSYM(.25,TITLE4,0.,3.375*DS,1.15)
      CALL   PLTSYM(.10,TITLE7,0.,2.05*DS,1.35)
      CALL   PLTSYM(.10,TITLE6,0.,2.25*DS,1.45)
      CALL   PLTSYM(.10,TITLE5,0.,2.25*DS,1.55)
      CALL   PLTSCA(XX,11.75,DMIN,0.,DS,.2)
      CALL   PLTDTS(3,14,MTBF,CKOUNT,NRMTBF,0)
      CALL   PLTAXS(DELD,.2,DMIN,DMAX,0.,1.,4)
      CALL   LABELA(DELD,.2,DMIN,DMAX,0.,1.,1.,1.)
      CALL   PLTSCA(XX,11.75,0.,0.,DS,.2)
      CALL   PLTSYM(.25,TITLE1,0.,3.875*DS,-.15)
      CALL   PLTSYM(.25,TITLE2,90.,-DS,.225)
      CALL   PLTSYM(.25,TITLE3,0.,3.125*DS,1.05)
      CALL   PLTSYM(.25,TITLE4,0.,3.375*DS,1.15)
490   MODE=MODE+1
      GOTO(500,510,520,530,560),MODE
500   CALL SUB3(NRITER,NRMTBF,NUMB)
      XX=17.
      GOTO 420
510   CALL SUB5(NRMTBF)
      XX=31.
      GOTO 420
520   CALL SUB7(NRMTBF)
      XX=45.
      GOTO 420
530   CALL SUB9(NRMTBF)
      XX=59.
      GOTO 420
540   WRITE(6,550)DELTAX
550   FORMAT('1',T4,'THE INCREMENT VALUE CHOSEN (',F10.2,
     $') FOR THE RANGE OF TRUE MTBFS CONSIDERED WAS TOO LARGE.'//T4,
     $'CHOOSE A SMALLER INCREMENT VALUE SUCH THAT THE INCREMENT ',
     $'VALUE MULTIPLIED BY FOUR (4) AND THEN SUBTRACTED'/T7,
     $'FROM YOUR BASE MTBF WILL RESULT IN A NUMBER THAT IS ',
     $'GREATER THAN ZERO.')
560   CALL   PLTPGE
      STOP
      END
      SUBROUTINE SUB1(NRITER,NRMTBF)
      COMMON      AKOUNT(500),BKOUNT(500)
      COMMON      CKOUNT(500),DKOUNT(500)
      ARITER=NRITER
      DO 5 N=1,NRMTBF
```

```
      CKOUNT(N)=AKOUNT(N+4)/ARITER
      DKOUNT(N)=BKOUNT(N+4)/ARITER
    5 CONTINUE
      RETURN
      END
      SUBROUTINE SUB3(NRITER,NRMTBF,NUMB)
      COMMON      AKOUNT(500),BKOUNT(500)
      COMMON      CKOUNT(500),DKOUNT(500)
      ARITER=NRITER
      DO 5 K=1,NUMB
      AKOUNT(K)=AKOUNT(K)/ARITER
      BKOUNT(K)=BKOUNT(K)/ARITER
    5 CONTINUE
      DO 10 I=1,NRMTBF
      CKOUNT(I)=(AKOUNT(I+3)+AKOUNT(I+5))/4.+(AKOUNT(I+4))/2.
      DKOUNT(I)=(BKOUNT(I+3)+BKOUNT(I+5))/4.+(BKOUNT(I+4))/2.
   10 CONTINUE
      RETURN
      END
      SUBROUTINE SUB5(NRMTBF)
      COMMON      AKOUNT(500),BKOUNT(500)
      COMMON      CKOUNT(500),DKOUNT(500)
      DO 5 I=1,NRMTBF
      CKOUNT(I)=(AKOUNT(I+2)+AKOUNT(I+6))/10.
     $          +(AKOUNT(I+3)+AKOUNT(I+5))/5.
     $          +(AKOUNT(I+4))*2./5.
      DKOUNT(I)=(BKOUNT(I+2)+BKOUNT(I+6))/10.
     $          +(BKOUNT(I+3)+BKOUNT(I+5))/5.
     $          +(BKOUNT(I+4))*2./5.
    5 CONTINUE
      RETURN
      END
      SUBROUTINE SUB7(NRMTBF)
      COMMON      AKOUNT(500),BKOUNT(500)
      COMMON      CKOUNT(500),DKOUNT(500)
      DO 5 K=1,NRMTBF
      CKOUNT(K)=(AKOUNT(K+1)+AKOUNT(K+7))/22.
     $          +(AKOUNT(K+2)+AKOUNT(K+6))/11.
     $          +(AKOUNT(K+3)+AKOUNT(K+5))*2./11.
     $          +(AKOUNT(K+4))*4./11.
      DKOUNT(K)=(BKOUNT(K+1)+BKOUNT(K+7))/22.
     $          +(BKOUNT(K+2)+BKOUNT(K+6))/11.
     $          +(BKOUNT(K+3)+BKOUNT(K+5))*2./11.
     $          +(BKOUNT(K+4))*4./11.
    5 CONTINUE
      RETURN
      END
      SUBROUTINE SUB9(NRMTBF)
      COMMON      AKOUNT(500),BKOUNT(500)
      COMMON      CKOUNT(500),DKOUNT(500)
      DO 5 I=1,NRMTBF
      CKOUNT(I)=(AKOUNT(I)+AKOUNT(I+8))/46.
     $          +(AKOUNT(I+1)+AKOUNT(I+7))/23.
     $          +(AKOUNT(I+2)+AKOUNT(I+6))*2./23.
     $          +(AKOUNT(I+3)+AKOUNT(I+5))*4./23.
     $          + AKOUNT(I+4)*8./23.
      DKOUNT(I)=(BKOUNT(I)+BKOUNT(I+8))/46.
     $          +(BKOUNT(I+1)+BKOUNT(I+7))/23.
     $          +(BKOUNT(I+2)+BKOUNT(I+6))*2./23.
     $          +(BKOUNT(I+3)+BKOUNT(I+5))*4./23. + BKOUNT(I+4)*8./23.
    5 CONTINUE
      RETURN
      END
?
        7      2000        5        8    45.00    745.00    10.00   100.00
     0.00      0.00      .57     2.22     3.87      5.52     7.17    10.35
```

3.75	5.40	7.05	9.70	10.35	10.35	10.35	10.35
41.	49.50	36.					
19.	21.90	15.					
16.	20.60	12.					
8.	9.74	5.					
7.	10.35	4.					
3.	4.50	2.					
6.	6.80	3.					
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